PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCLXVI.

LIBRARY
UNIVERSITY OF TORONTO

VOL. 156.

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

MDCCCLXVI.

Q
41
L8
v. 156

LIBRARY
FEB 27 1963
UNIVERSITY OF TORONTO

829682

CONTENTS

OF VOL. 156.

I. *On Calorescence. By Professor* J. Tyndall, *LL.D. Camb., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines* . . . . page 1

II. *A Supplementary Memoir on the Theory of Matrices. By* A. Cayley, *Esq., F.R.S.* 25

III. *Synthetical Researches on Ethers.*—No. 1. *Synthesis of Ethers from Acetic Ether. By* E. Frankland, *F.R.S., and* B. F. Duppa, *Esq.* 37

IV. *On the Fossil Mammals of Australia.*—Part II. *Description of an almost entire Skull of the* Thylacoleo carnifex, Owen, *from a freshwater deposit, Darling Downs, Queensland. By Professor* Owen, *F.R.S., &c.* 73

V. *Sixth Memoir on Radiation and Absorption.—Influence of Colour and Mechanical Condition on Radiant Heat. By Professor* J. Tyndall, *LL.D., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines* 83

VI. *Addition to the Memoir on* Tschirnhausen's *Transformation. By* Arthur Cayley, *F.R.S.* 97

VII. *On the Development of Striated Muscular Fibre. By* Wilson Fox, *M.D. Lond., Professor of Pathological Anatomy at University College, London. Communicated by Dr.* Sharpey, *Sec. R.S.* 101

VIII. *On the Structure and Development of the Skull in the Ostrich Tribe. By* William Kitchen Parker, *F.Z.S. Communicated by Professor* T. H. Huxley, *F.R.S.* 113

IX. *Account of Experiments on the Flexural and Torsional Rigidity of a Glass Rod, leading to the Determination of the Rigidity of Glass. By* JOSEPH D. EVERETT, *D.C.L., Assistant to the Professor of Mathematics in the University of Glasgow. Communicated by Professor* W. THOMSON, *F.R.S.* . . . . page 185

X. *On the Laws of Connexion between the Conditions of a Chemical Change and its Amount. By* A. VERNON HARCOURT, *M.A., Student of Christ Church, and Demonstrator of Chemistry in the University of Oxford; and* WILLIAM ESSON, *M.A., Fellow of Merton College, Oxford. Communicated by Sir* B. C. BRODIE, *Bart., F.R.S., Professor of Chemistry in the University of Oxford* 193

XI. *On the Chameleon's Retina; a further Contribution to the Minute Anatomy of the Retina of Reptiles. By* J. W. HULKE, *F.R.C.S., Assistant Surgeon to the Middlesex and Royal London Ophthalmic Hospitals. Communicated by* WILLIAM BOWMAN, *F.R.S.* 223

XII. *On the Expansion by Heat of Water and Mercury. By* A. MATTHIESSEN, *F.R.S.* 231

XIII. THE BAKERIAN LECTURE.—*On the Viscosity or Internal Friction of Air and other Gases. By* J. CLERK MAXWELL, *M.A., F.R.S.* 249

XIV. *Researches on Gun-cotton.—On the Manufacture and Composition of Gun-cotton. By* F. A. ABEL, *F.R.S., V.P.C.S.* 269

XV. *Researches on Acids of the Lactic Series.*—No. I. *Synthesis of Acids of the Lactic Series. By* E. FRANKLAND, *F.R.S., Professor of Chemistry in the Royal Institution of Great Britain and in the Government School of Mines; and* B. F. DUPPA, *Esq.* 309

XVI. *Fundamental Views regarding Mechanics. By Dr.* J. PLÜCKER, *of Bonn, For. Memb. R.S.* 361

XVII. *Further Observations on the Spectra of some of the Nebulæ, with a Mode of determining the Brightness of these Bodies. By* WILLIAM HUGGINS, *F.R.S.* . 381

XVIII. *On the Absorption and Dialytic Separation of Gases by Colloid Septa. By* THOMAS GRAHAM, *F.R.S., Master of the Mint* 399

XIX. *Results of the Magnetic Observations at the Kew Observatory.*—No. III. *By Lieut.-General* EDWARD SABINE, *R.A., President of the Royal Society* . . 441

XX. *Contributions to Terrestrial Magnetism.*—No. X. *By Lieut.-General* EDWARD SABINE, *R.A., President of the Royal Society* 453

XXI. *On the Anatomy and Physiology of the Nematoids, Parasitic and Free; with observations on their Zoological Position and Affinities to the Echinoderms. By* H. CHARLTON BASTIAN, *M.A., M.B. Lond., F.L.S.* 545

XXII. *On the Tides of the Arctic Seas. By the Rev.* SAMUEL HAUGHTON, *M.D., F.R.S., Fellow of Trinity College, Dublin.*—Part III. *On the Semidiurnal Tides of Frederiksdal, near Cape Farewell, in Greenland* . . . . page 639

XXIII. *On Uniform Rotation. By* C. W. SIEMENS, *F.R.S., Mem. Inst. C.E.* . 657

XXIV. *Researches on the Structure, Physiology, and Development of* Antedon (Comatula, *Lamk.*) rosaceus.—Part I. *By* WILLIAM B. CARPENTER, *M.D., F.R.S.* 671

XXV. *On the Motion of a Rigid Body acted on by no external Forces. By* J. J. SYLVESTER, *LL.D., F.R.S.* 757

XXVI. *The Calculus of Chemical Operations; being a Method for the Investigation, by means of Symbols, of the Laws of the Distribution of Weight in Chemical Change.* —Part I. *On the Construction of Chemical Symbols. By Sir* B. C. BRODIE, *Bart., F.R.S., Professor of Chemistry in the University of Oxford* 781

XXVII. *On the Expansion by Heat of Metals and Alloys. By* A. MATTHIESSEN, *F.R.S.* 861

Index 883

APPENDIX.

Presents . . . . [1]

LIST OF ILLUSTRATIONS.

Plate I.—Professor TYNDALL on Calorescence.

Plates II. to IV.—Professor OWEN on the Fossil Mammals of Australia.

Plates V. & VI.—Dr. WILSON FOX on the Development of Striated Muscular Fibre.

Plates VII. to XV.—Mr. W. K. PARKER on the Structure and Development of the Skull in the Ostrich Tribe.

Plate XVI.—Dr. EVERETT on the Rigidity of Glass.

Plates XVII. & XVIII.—Messrs. A. V. HARCOURT and W. ESSON on the Laws of Connexion between the Conditions of a Chemical Change and its Amount.

Plate XIX.—Mr. J. W. HULKE on the Chameleon's Retina.

Plate XX.—Dr. A. MATTHIESSEN on the Expansion of Heat by Water and Mercury.

Plate XXI.—Mr. CLERK MAXWELL on the Viscosity or Internal Friction of Air and other Gases.

Plates XXII. to XXVIII.—Dr. H. CHARLTON BASTIAN on the Anatomy and Physiology of the Nematoids, Parasitic and Free.

Plates XXIX. & XXX.—Mr. C. W. SIEMENS on Uniform Rotation.

Plates XXXI. to XLIII.—Dr. W. B. CARPENTER on the Structure, Physiology, and Development of Antedon (Comatula, *Lamk.*) rosaceus.

PHILOSOPHICAL TRANSACTIONS.

I. *On Calorescence. By Professor* J. Tyndall, *LL.D. Camb., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines.*

Received October 20,—Read November 23, 1865.

> Forsitan et roseâ sol altè lampade lucens
> Possideat multum cæcis fervoribus ignem
> Circum se, nullo qui sit fulgore notatus,
> Æstiferum ut tantum radiorum exaugeat ictum.
>
> Lucret. v. 610[*].

§ 1.

In the year 1800, and in the same volume of the Philosophical Transactions that contains Volta's celebrated letter to Sir Joseph Banks on the Electricity of Contact[†], Sir William Herschel published his discovery of the invisible rays of the sun. Causing thermometers to pass through the various colours of the solar spectrum, he determined their heating-power, and found that this power, so far from ending at the red extremity of the spectrum, rose to a maximum at some distance beyond the red. The experiment proved that, besides its luminous rays, the sun emitted others of low refrangibility, which possessed great calorific power, but were incompetent to excite vision.

Drawing a datum-line to represent the length of the spectrum, and erecting at various points of this line perpendiculars to represent the calorific intensity existing at those points, on uniting the ends of the perpendiculars Sir William Herschel obtained the subjoined curve (fig. 1), which shows the distribution of heat in the solar spectrum, according to his observations. The space A B D represents the invisible, and B D E the visible radiation of the sun. With the more perfect apparatus subsequently devised, Professor Müller of Freiburg examined the distribution of heat in the spectrum[‡], and the results of his observations are rendered graphically in fig. 2. Here the area A B C D represents the invisible, while C D E represents the visible radiation.

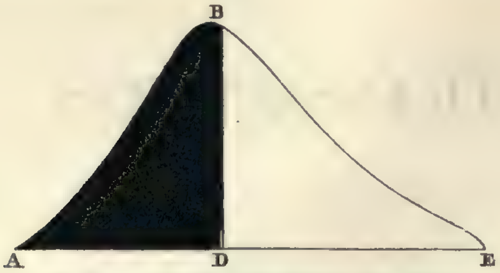
---

[*] I am indebted to my excellent friend Sir Edmund Head for this extract, which reads like divination.

[†] Vol. lxx.

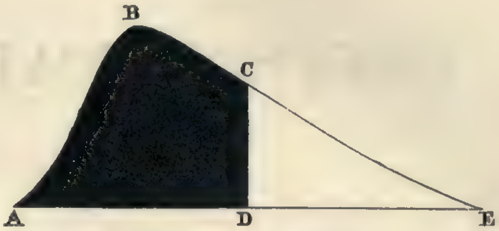
[‡] Philosophical Magazine, Ser. 4. vol. xvii. p. 242.

Fig. 1.



Spectrum of Sun (Herschel) reduced.

Fig. 2.



Spectrum of Sun (Müller).

With regard to terrestrial sources of heat, it may be stated that all such sources hitherto examined emit those obscure rays. Melloni found that 90 per cent. of the emission from an oil-flame, 98 per cent. of the emission from incandescent platinum, and 99 per cent. of the emission from an alcohol-flame consists of obscure rays*. The visible radiation from a hydrogen-flame is, according to my own experiments, too small to admit of measurement. With regard to solid bodies, it may be stated generally that, when they are raised from a state of obscurity to vivid incandescence, the invisible rays emitted in the first instance continue to be emitted with augmented power when the body glows. For example, with a current of feeble power the carbons of the electric lamp may be warmed and caused to emit invisible rays. But the intensity of these same rays may be augmented a thousandfold by raising the carbons to the temperature necessary for the electric light. Here, in fact, the luminous and non-luminous emission augment together, the maximum of brightness of the visible rays occurring simultaneously with the maximum calorific power of the invisible ones†.

At frequent intervals during the past ten or twelve years I have had occasion to experiment on the invisible rays of the electric light, and have finally made them the subject of special investigation. The present paper contains a brief account of the inquiry. I endeavour, in the first place, to compare the luminous with the non-luminous radiation of the electric light, and to determine their relative energy; I point out a method of detaching the luminous from the non-luminous rays; and afterwards describe various experiments illustrative of the calorific power of the invisible rays, and of the transmutations of which they are capable.

§ 2.

The instrument employed by Professor Müller in the investigation above alluded to, was a form of the thermo-electric pile devised by Melloni for the examination of this and kindred questions. Through the kindness of my friend Mr. Gassiot, a very beautiful instrument of this kind, constructed by Ruhmkorff, has remained in my possession for several years, and been frequently employed in my researches. It consists of a double metallic screen, with a rectangular aperture in the centre—a single row of thermo-electric elements 1·2 inch in length being fixed to the screen behind the aperture. Connected with the latter are two moveable side pieces, which can be caused to approach or recede so as to vary the width of the exposed face of the pile from zero to $\frac{1}{10}$th of an inch. The instrument is mounted on a slider, which, by turning a handle, is moved along a slot on a massive metal stand. A spectrum of a width equal to the length of the thermo-electric pile being cast at the proper elevation on the screen, by turning the handle of the slider the vertical face of the pile can be caused to traverse the colours, and also the spaces right and left of them.

---

* La Thermochrose, p. 304.

† On this point see the Rede Lecture for 1865, p. 33 (Longmans).

To produce a steady spectrum of the electric light, I employed the regulator devised by M. FOUCAULT and constructed by DUBOSCQ, the constancy of which is admirable. A complete rock-salt train was constructed for me by Mr. BECKER, and arranged in the following manner. In the front orifice of the camera which surrounds the electric lamp was placed a lens of transparent rock-salt, intended to reduce to parallelism the divergent rays proceeding from the carbon-points. The parallel beam was permitted to pass through a narrow slit, in front of which was placed another rock-salt lens, the position of this lens being so arranged that a sharply defined image* of the slit was obtained at a distance beyond it equal to that at which the spectrum was to be formed. Immediately behind this lens was placed a pure rock-salt prism (sometimes two of them). The beam was thus decomposed, a brilliant horizontal spectrum being cast upon the screen which bore the thermo-electric pile. By turning the handle already referred to, the face of the pile could be caused to traverse the spectrum, an extremely narrow band of light or radiant heat falling upon it at each point of its march †. A sensitive galvanometer was connected with the pile, and from its deflection the heating-power of every part of the spectrum, visible and invisible, was determined.

Two modes of moving the instrument were practised. In the first the face of the pile was brought up to the violet end of the spectrum, where the heat was insensible, and then moved through the colours to the red, then past the red up to the position of maximum heat, and afterwards beyond this position until the heat of the invisible spectrum gradually faded away. The following Table contains a series of measurements executed in this manner. The motion of the pile is measured by turns of its handle, every turn corresponding to the shifting of the face of the instrument through a space of one millimetre, or $\frac{1}{25}$th of an inch. At the beginning, where the increment of heat was slow and gradual, the readings were taken at every two turns of the handle; on quitting the red, where the heat suddenly increases, the intervals were only half a turn, while near the maximum, where the changes were most sudden, the intervals were reduced to a quarter of a turn, which corresponded to a translation of the pile through $\frac{1}{100}$th of an inch. Intervals of one and of two turns were afterwards resumed until the heating-power ceased to be distinct. At every halting-place the deflection of the needle was noted, the value of the deflection, referred to the first degree as unit, being placed in the first column of figures in the Table. It was found convenient to call the maximum effect in each series of experiments 100; the second column of figures, obtained by multiplying the first by the constant factor 1·37, expresses the heat of all the parts of the spectrum with reference to this maximum.

---

* The width of the image was about 0·1 of an inch.

† The width of the linear pile was 0·03 of an inch.

TABLE I.—Distribution of Heat in Spectrum of Electric Light.

Movement of pile.	Value of deflection.	Calorific intensity, in 100ths of the maximum.
Before starting (pile in the blue) . .	0·0	0·0
Two turns forward (green entered) .	1·5	2·0
,, ...	3·5	4·8
,, ...	5·5	7·5
,, (red entered) . .	15·5	21·0
,, (extreme red) . .	32·6	44·6
Half turn forward	44·0	60·0
,, ...	54·0	74
,, ...	62·0	85
,, ...	70·0	95·8
,, ...	72·5	99
Quarter turn forward, *maximum* . .	73·0	100·0
,, ...	70·8	97·0
Half turn forward	57·0	78·0
,, ...	45·5	62·0
,, ...	32·6	44·5
,, ...	26·0	35·6
Two turns forward	10·5	14·4
,, ...	6·5	9
,, ...	5·0	6·8
,, ...	3·5	5
,, ...	2·5	3·4
,, ...	1·7	2·3
,, ...	1·3	1·8

Here, as before stated, we begin in the blue, and pass first through the visible spectrum. Quitting this at the place marked "(extreme red)," we enter the invisible calorific spectrum and reach the position of maximum heat, from which, onwards, the thermal power falls till it practically disappears.

In other observations the pile was first brought up to the position of maximum heat, and moved thence to the extremity of the spectrum in one direction. It was then brought back to the maximum, and moved to the extremity in the other direction. There was generally a small difference between the two maxima, arising, no doubt, from some slight alteration of the electric light during the period which intervened between the two observations. The following Table contains the record of a series of such measurements. As in the last case, the motion of the pile is measured by turns of the handle, and the values of the deflections are given with reference to a maximum of 100.

TABLE II.—Distribution of Heat in Spectrum of Electric Light.

Movement of pile.	Calorific intensity, in 100ths of the maximum.
Maximum	100
One turn *towards* visible spectrum	94·4
,, ,,	65·5
,, ,,	42·6
,, ,, (extreme red)	28·3
,, ,,	20·0
,, ,,	14·8
,, ,,	11·1
Two turns in the same direction (green entered)	7·4
,, ,,	4·6
,, ,,	2·0
,, ,, (pile in blue)	0·9
Pile brought back to maximum.	
Maximum	100·0
One turn *from* visible spectrum	67·1
,, ,,	41·0
,, ,,	23·0
,, ,,	13·0
,, ,,	9·4
Two turns	5·0
,,	3·4
,,	0·0

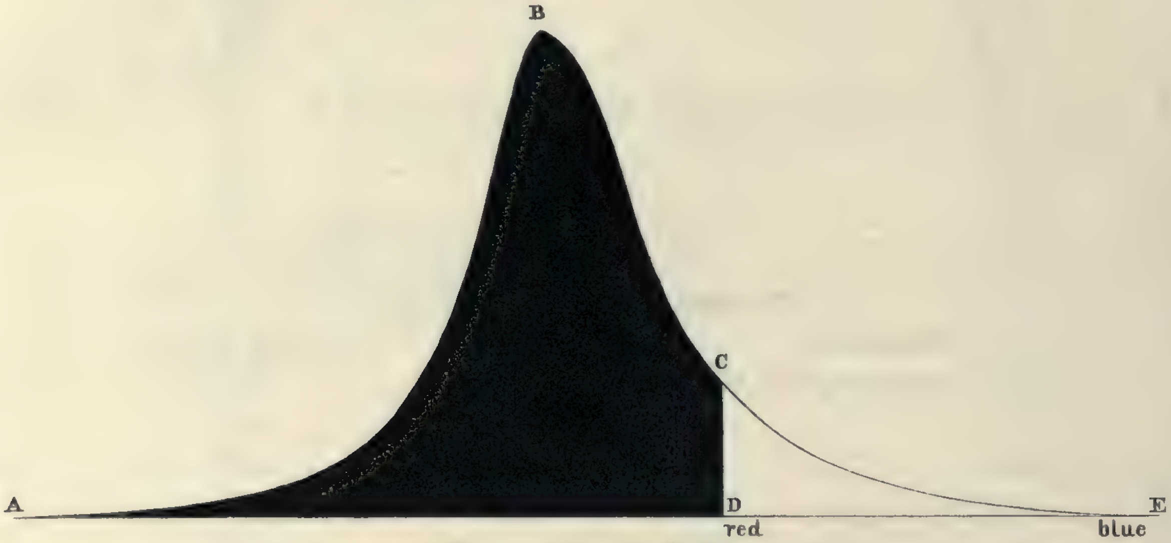
More than a dozen series of such measurements were executed, each series giving its own curve. On superposing the different curves, however, a very close agreement was found to exist between them. The annexed curve (fig. 3), which is the mean of several, expresses, with a close approximation to accuracy, the distribution of heat in the spectrum of the electric light from fifty cells of GROVE. The space A B C D represents the invisible, while C D E represents the visible radiation. We here see the gradual augmentation of thermal power, from the blue end of the spectrum to the red. But in the region of dark rays beyond the red the curve shoots suddenly upwards in a steep and massive peak, which quite dwarfs by its magnitude the portion of the diagram representing the visible radiation*.

---

* How are we to picture the vibrating atoms which produce the different wave-lengths of the spectrum?

The sun's rays before reaching the earth have to pass through our atmosphere, where they encounter the atmospheric aqueous vapour, which exercises a powerful absorption on the invisible calorific rays. From this, apart from other considerations, it would follow that the ratio of the invisible to the visible radiation in the case of the sun must be less than in the case of the electric light. Experiment, we see, justifies this conclusion; for, whereas fig. 2 shows the invisible radiation of the sun to be about twice the visible, fig. 3 shows the invisible radiation of the electric light to be nearly eight times the visible. If we cause the beam from the electric lamp to pass through a layer of water of suitable thickness, we place its radiation in approximately the same condition as that of the sun; and on decomposing the beam after it has been thus sifted, we obtain a distribution of heat closely resembling that observed in the solar spectrum.

Fig. 3.



Spectrum of electric light.

Does the infinity of the latter, between the extreme ends of the spectrum, answer to an infinity of atoms each oscillating at a single rate? or are we not to figure the atoms as virtually capable of oscillating at different rates at the same time? When a sound and its octave are propagated through the same mass of air, the resultant motion of the air is the algebraic sum of the two separate motions impressed upon it. The ear decomposes this motion into its two components (Helmholtz, Ton-Empfindungen, p. 54); still we cannot here figure certain particles of the air occupied in the propagation of the one sound, and certain other particles in the propagation of the other. May not what is true of the air be true of the ether? and may not, further, a single atom, controlled and jostled as it is in solid bodies by its neighbours, be able to impress upon the ether a motion equivalent to the sum of the motions of several atoms each oscillating at one rate?

It is perhaps worthy of remark, that there appears to be a definite rate of vibration for all solid bodies having the same temperature, at which the *vis viva* of their atoms is a maximum. If, instead of the electric light, we examine the lime-light, or a platinum wire raised to incandescence by an electric current, we find the apex of the curve of distribution (B, fig. 3) corresponding throughout to very nearly, if not exactly, the same refrangibility. There seems, therefore, to exist one special rate at which the atoms of heated solids oscillate with greater energy than at any other rate—a non-visual period, which lies about as far from the extreme red of the spectrum on the invisible side as the commencement of the green on the visible one.

The curve representing the distribution of heat in the electric spectrum falls most steeply on that side of the maximum which is most distant from the red. On both sides, however, we have a *continuous* falling off. I have had numerous experiments made to ascertain whether there is any interruption of continuity in the calorific spectrum; but all the measurements hitherto executed with artificial sources reveal a gradual and continuous augmentation of heat from the point where it first becomes sensible up to the maximum. Sir JOHN HERSCHEL has shown that this is not the case with the radiation from the sun when analyzed by a flint-glass prism. Permitting the solar spectrum to fall upon a sheet of blackened paper, over which had been spread a wash of alcohol, this eminent philosopher determined by its drying-power the heating-power of the spectrum. He found that the wet surface dried in a series of spots representing thermal maxima separated from each other by spaces of comparatively feeble calorific intensity. No such maxima and minima were observed in the spectrum of the electric light, nor in the spectrum of a platinum wire raised to a white heat by a voltaic current. Prisms and lenses of rock-salt, of crown glass, and of flint glass were employed in these cases. In subsequent experiments the beam intended for analysis was caused to pass through layers of water and other liquids of various thicknesses. Gases and vapours of various kinds were also introduced into the path of the beam. In all cases there was a general lowering of the calorific power, but the descent of the curve on both sides of the maximum was unbroken*.

§ 3.

The rays from an obscure source cannot compete in point of intensity with the obscure rays of a luminous source. No body heated under incandescence could emit rays of an intensity comparable to those of the maximum region of the electric spectrum. If, therefore, we wish to produce intense calorific effects by invisible rays, we must choose those emitted by an intensely luminous source. The question then arises, how are the invisible calorific rays to be isolated from the visible ones. The interposition of an opaque screen suffices to cut off the visible spectrum of the electric light, and leaves us the invisible calorific rays to operate upon at our pleasure. Sir WILLIAM HERSCHEL experimented thus when he sought, by concentrating them, to render the invisible rays of the sun visible. But to form a spectrum in which the invisible rays shall be completely separated from the visible ones, a narrow slit or a small aperture is necessary; and this circumstance renders the amount of heat separable by prismatic analysis very limited. If we wish to ascertain what the intensely concentrated invisible rays can accomplish, we must devise some other mode of detaching them from their visible companions. We must, in fact, discover a substance which shall filter the composite radiation of a luminous source by stopping the visible rays and allowing the invisible ones free transmission.

Could we obtain a *black* elementary body thoroughly homogeneous, and with all its parts in perfect optical contact, experiments already published would lead me to expect that such a body would form an effectual filter for the radiation of the sun or of the electric light. While cutting off the visible radiation, the black element would, I imagine, allow the invisible to pass. Carbon in the state of soot is black, but its parts are not optically continuous. In black glass the continuity is far more perfect, and hence the result established by Melloni, that black glass possesses a considerable power of transmission. Gold in ruby glass, or in the state of jelly prepared by Mr. Faraday, is exceedingly transparent to the invisible calorific rays, but it is not black enough to quench entirely the visible ones. The densely brown liquid bromine is better suited to our purpose; for, in thicknesses sufficient to quench the light of our brightest flames, this element displays extraordinary diathermancy. Iodine cannot be applied in the solid condition, but it dissolves freely in various liquids, the solution in some cases being intensely dark. Here, however, the action of the element may be masked by that of its solvent. Iodine, for example, dissolves freely in alcohol; but alcohol is so destructive of the extra-red rays, that it would be entirely unfit for experiments the object of which is to retain these rays while quenching the visible ones. The same remark applies in a greater or less degree to many other solvents of iodine.

---

* At a future day I hope to subject this question to a more severe examination.

The deportment of bisulphide of carbon, both as a vapour and a liquid, suggests the thought that it would form a most suitable solvent. It is extremely diathermic, and there is hardly another substance able to hold so large a quantity of iodine in solution. Experiments already recorded prove that, of the rays emitted by a red-hot platinum spiral, 94·5 per cent. is transmitted by a layer of the liquid 0·02 of an inch in thickness, the transmission through layers 0·07 and 0·27 of an inch thick being 87·5 and 82·5 respectively*. The following experiment with a layer of far greater thickness exhibits the deportment of the transparent bisulphide towards the more intense radiation of the electric light. A cylindrical cell, 2 inches in length and 2·8 inches in diameter, with its ends stopped by plates of perfectly transparent rock-salt, was placed empty in front of an electric lamp; the radiation from the lamp, after having crossed the cell, fell upon a thermo-electric pile, and produced a deflection of

73°.

Leaving the cell undisturbed, the transparent bisulphide of carbon was poured into it: the deflection fell to

72°.

A repetition of the experiment gave the following results:—

	Deflection.
Through empty cell	74°
Through bisulphide	73

Taking the values of these deflections from a Table of calibration and calculating the transmission, that through the empty cell being 100, we obtain the following results:—

---

* Philosophical Transactions, vol. cliv. p. 333; Philosophical Magazine, Ser. 4. vol. xxviii. p. 446.

	Transmission.
For the first experiment	94·9
For the second experiment	94·6
Mean	94·8

Hence the introduction of the bisulphide lowers the transmission only from 100 to 94·8*.

A *perfect* solvent of the iodine would be perfectly neutral to the total radiation; and the bisulphide of carbon is shown by the foregoing experiment to approach tolerably near perfection. We have in it a body capable of transmitting with little loss the total radiation of the electric light. Our object is now to filter this total, by the introduction into the bisulphide of a substance competent to quench the visible and transmit the invisible rays. Iodine does this with marvellous sharpness. In a short paper "On Luminous and Obscure Radiation," published in the Philosophical Magazine for November 1864, the diathermancy of this substance is illustrated by the following Table:—

TABLE III.—Radiation through dissolved Iodine.

Source.	Transmission.
Dark spiral of platinum wire	100
Lampblack at 212° Fahr.	100
Red-hot platinum spiral	100
Hydrogen-flame	100
Oil-flame	97
Gas-flame	96
White-hot spiral	95·4
Electric light, battery of 50 cells	90

These experiments were made in the following way:—A rock-salt cell was first filled with the transparent bisulphide, and the quantity of heat transmitted by the pure liquid to the pile was determined. The same cell was afterwards filled with the opaque solution, the transmission through which was also determined. Calling the transmission through the transparent liquid 100, the foregoing Table gives the transmission through the opaque. The results, it is plain, refer solely to the iodine dissolved in the bisulphide,—the transmission 100, for example, indicating, not that the solution itself, but that the body dissolved is, within the limits of error, perfectly diathermic to the radiation from the first four sources.

The layer of liquid employed in these last experiments was not sufficiently thick to quench utterly the luminous radiation from the electric lamp. A cell was therefore constructed whose parallel faces were 2·3 inches apart, and which, when filled with the solution of iodine, allowed no trace of the most highly concentrated luminous beam to pass through it. Five pairs of experiments executed with this cell yielded the following results:—

---

* The partial destruction of the reflexion from the sides of the cell by the introduction of the bisulphide is not here taken into account.

Radiation from Electric Light; battery 40 cells.

	Deflection.
Through transparent bisulphide	47°·0; 46°·0
Through opaque solution	42·3; 43·5
Through transparent bisulphide	44·0; 43·7
Through opaque solution	41·2; 40·0
Through transparent bisulphide	42·0; 43·0

Calling the transmission through the transparent liquid 100, and taking the mean of all these determinations, the transmission through the opaque solution is found by calculation to be 86·8. An absorption of 13·2 per cent. is therefore to be set down to the iodine. This was the result with a battery of forty cells; subsequent experiments with a battery of fifty cells made the transmission 89 and the absorption 11.

Considering the transparency of the iodine for heat emitted by all sources heated up to incandescence, as exhibited in Table III., it may be inferred that the above absorption of 11 per cent. represents the calorific intensity of the *luminous rays* alone. By the method of filtering, therefore, we make the invisible radiation of the electric light eight times the visible. Computing, by means of a proper scale, the area of the spaces A B C D, C D E (fig. 3), the former, which represents the invisible emission, is found to be 7·7 times the latter. Prismatic analysis, therefore, and the method of filtering yield almost exactly the same result.

§ 4.

In the combination of bisulphide of carbon and iodine we find a means of filtering the composite radiation from any luminous source. The solvent is practically transparent, while the dissolved iodine cuts off every visible ray, its absorptive power ceasing with extraordinary suddenness at the extreme red of the spectrum. Doubtless the absorption extends a little way beyond the red, and with a very great thickness of solution the absorption of the extra-red rays might become very sensible. But the solution may be employed in layers which, while competent to intercept every trace of light, allow the invisible calorific rays to pass with scarcely sensible diminution.

The *ray-filter* here described was first publicly employed in the early part of 1862*. Concentrating by large glass lenses the radiation of the electric lamp, I cut off the visible portion of the radiation by the solution of iodine, and thus formed invisible foci of an intensity at that time unparalleled. In the autumn of 1864 similar experiments were executed with rock-salt lenses and with mirrors. The paper "On Luminous and Obscure Radiation," already referred to, contains an account of various effects of combustion and fusion which were then obtained with the invisible rays of the electric light and of the sun*.

---

* Philosophical Transactions, 1862, p. 67, note.

From the setting of paper on fire, and the fusion of non-refractory metals, to the rendering of refractory bodies incandescent, the step was immediate. To avoid waste by conduction, it was necessary to employ the metals in plates as thin as possible. A few preliminary experiments with platinum foil, which resulted in failure, raised the question whether, even with the *total radiation* of the electric light, it would be possible to obtain incandescence without combustion. Abandoning the use of lenses altogether, I caused a thin leaf of platinum to approach the ignited coal points. It was observed by myself from behind, while my assistant stood beside the lamp, and, looking through a dark glass, observed the distance between the platinum foil and the electric light. At half an inch from the carbon points the metal became red-hot. The problem now was to obtain, at a greater distance, a focus which should possess a heating-power equal to that of the direct rays at a distance of half an inch.

In the first attempt the direct rays were utilized as much as possible. A piece of platinum foil was placed at a distance of an inch from the carbon points, there receiving the direct radiation. The rays emitted *backwards* from the points were at the same time converged by a small mirror upon the foil, and were found more than sufficient to compensate for the diminution of intensity due to the withdrawal of the foil to the distance of an inch. By the same method incandescence was subsequently obtained when the foil was removed two, and three, inches from the carbon points.

The last-mentioned distance allowed me to introduce between the focus and the source of rays a cell containing the solution of iodine. The transmitted obscure rays were found of sufficient power to inflame paper, or to raise platinum foil to incandescence.

These experiments, however, were not unattended with danger. The bisulphide of carbon is an extremely inflammable substance; and on the 2nd of November, while employing a very powerful battery and intensely heated carbon points, the solution took fire, and instantly enveloped the electric lamp and all its appurtenances in flame. The precaution, however, had been taken of placing the entire apparatus in a flat vessel containing water, into which the flaming mass was summarily turned. The bisulphide of carbon being heavier than the water, sank to the bottom, so that the flames were speedily extinguished. Similar accidents occurred twice subsequently.

---

* To the experiments there described the following may be added, as made at the time. A glass globe, 3¾ inches in diameter, was filled with the opaque solution, and placed in front of the electric light. An intense focus of invisible rays was formed immediately beyond the globe. Black paper held in this focus was pierced, a burning ring being produced. A second spherical flask, 9 inches in diameter, was filled with the solution and employed as a lens. The effects, however, were less powerful than those obtained with the smaller flask.

Two plano-convex lenses of rock-salt, 3 inches in diameter, were placed with their flat surfaces opposite, but separated from each other by a brass ring ⅜ths of an inch thick. The space between the plates was filled with the solution, and thus an opaque lens was formed. Paper was fired by this lens. In none of these cases, however, could the paper be caused to blaze. Hollow plano-convex lenses filled with the solution were not effective, the focal length of those at my disposal being too great.

Mr. Mayall was so extremely obliging as to transfer his great photographic camera from Brighton to London, for the purpose of enabling me to operate with the fine glass lens, 20 inches in diameter, which belonged to it: the result was not successful. It will, however, be subsequently shown that both the hollow lens and the glass lens are effective when, instead of the divergent rays of the electric lamp, we employ the parallel rays of the sun.

Such occurrences caused me to seek earnestly for a substitute for the bisulphide. Pure chloroform, though not so diathermic, transmits the obscure rays pretty copiously, and it freely dissolves iodine. In layers of the thickness employed, however, the solution was not sufficiently opaque; and in consequence of its absorptive power, but comparatively feeble effects were obtained with it. The same remark applies to the iodides of methyl and ethyl, to benzol, acetic ether, and other substances. They all dissolve iodine, but they enfeeble the results by their action on the extra-red rays.

I had special cells constructed for bromine and chloride of sulphur; neither of these substances is inflammable, but they are both intensely corrosive, and their action upon the lungs and eyes is so irritating as to render their employment impracticable. With both of these liquids powerful effects were obtained; still their diathermancy, though very high, did not come up to that of the dissolved iodine. Bichloride of carbon would be invaluable if its solvent power were equal to that of the bisulphide. It is not at all inflammable, and its own diathermancy appears to excel that of the bisulphide. But in reasonable thicknesses the iodine which it can dissolve is not sufficient to render the solution perfectly opaque. The solution forms a purple colour of indescribable beauty. Though unsuited to strict crucial experiments on dark rays, this filter may be employed with good effect in class experiments.

Thus foiled in my attempts to obtain a solvent equally good and less dangerous than the bisulphide of carbon, I sought to reduce to a minimum the danger of employing this substance. At an early period of the investigation I had constructed a tin camera, within which were placed both the lamp and its mirror. Through an aperture in front, 2¾ inches wide, the cone of reflected rays issued, forming a focus outside the camera. Underneath this aperture was riveted a stage, on which the solution of iodine rested, closing the aperture and cutting off all the light. In the first experiments nothing intervened between the cell and the carbon points; but the peril of thus exposing the bisulphide caused me to make the following improvements. First, a perfectly transparent plate of rock-salt, secured in a proper cap, was employed to close the aperture; and by it all direct communication between the solution and the incandescent carbons was cut off. The camera itself, however, became quickly heated by the intense radiation falling upon it, and the cell containing the solution was liable to be warmed both by the camera and by the luminous rays which it absorbed. The aperture above referred to was therefore surrounded by an annular space, about 2½ inches wide and a quarter of an inch deep, through which cold water was caused to circulate. The cell containing the solution was moreover surrounded by a jacket, and the current, having completed its course round the aperture, passed round the solution. Thus the apparatus was kept cold. The neck of the cell was stopped by a closely-fitting cork; through this passed a piece of glass tubing, which, when the cell was placed upon its stage, ended at a considerable distance from the focus of the mirror. Experiments on combustion might therefore be carried on at the focus without fear of igniting the small amount of vapour which even under the improved conditions might escape from the bisulphide of carbon. The arrangement will be at once understood by reference to Plate I. figs. 4 *a* & *b*, which show the camera, lamp, and filter both from the side and from the front. *x y* is the mirror from which the reflected cone of rays passes, first through the rock-salt window (unshaded), and afterwards through the iodine filter *m n*. The rays converge to the focus *k*, where they would form an invisible image of the lower carbon point; the image of the upper would be thrown below *k*; and both images spring vividly forth when a leaf of platinized platinum is exposed at the focus. At *s s* (Plate I. fig. 4 *a*) is shown, in section, the annular space in which the cold water circulates. Fig. 4 *b* (Plate I.) shows the manner in which the water enters this space and passes from it to the jacket surrounding the iodine-cell *m*.

With this arrangement, and a battery of fifty cells, the following results were obtained:—

A piece of silver-leaf, fastened to a wire ring and tarnished by exposure to the fumes of sulphide of ammonium, being held in the dark focus, the film flashed out occasionally into vivid redness.

Copper-leaf tarnished in a similar manner, when placed at the focus, was raised to redness.

A piece of platinized platinum foil was supported in an exhausted receiver, the vessel being so placed that the focus fell upon the platinum. The heat of the focus was instantly converted into light, a clearly defined and inverted image of the points being stamped upon the metal. Fig. 5 (Plate I.) represents the thermograph of the carbons.

Blackened paper was now substituted for the platinum in the exhausted receiver. Placed at the focus of invisible rays, the paper was instantly pierced, a cloud of smoke was poured through the opening, and fell like a cascade to the bottom of the receiver. The paper seemed to burn without incandescence. Here also a thermograph of the coal points was stamped out. When black paper is placed at the focus, where the thermal image is well defined, it is always pierced in two points, answering to the images of the two carbons. The superior heat of the positive carbon is shown by the fact that its image first pierces the paper; it burns out a large space, and shows its peculiarly crater-like top, while the negative carbon usually pierces a small hole.

Paper reddened by the iodide of mercury had its colour discharged at the places on which the invisible image of the coal points fell upon it.

Disks of paper reduced to carbon by different processes were raised to brilliant incandescence, both in the air and in the exhausted receiver.

In these earlier experiments I made use of apparatus which had been constructed for other purposes. The mirror, for example, was detached from a DUBOSCQ's camera, first silvered at the back, but afterwards silvered in front. The cell employed for the iodine solution was also that which usually accompanies DUBOSCQ's lamp, being intended by its maker for a solution of alum. Its sides are of good white glass, the width from side to side being 1·2 inch.

§ 5.

A point of considerable theoretic importance was involved in these experiments. In his excellent researches on fluorescence, Professor STOKES had invariably found the refrangibility of the incident light to be *lowered*. This rule was so constant as almost to enforce the conviction that it was a law of nature. But if the rays which in the foregoing experiments raised platinum and gold and silver to a red heat were wholly extra-red, the rendering visible of the metallic films would be an instance of *raised* refrangibility.

And here I thought it desirable to make sure that no trace of the visible radiation passed through the solution, and also that the invisible radiation was exclusively extra-red.

This latter condition might seem to be unnecessary, because the calorific action of the extra-violet rays is so exceedingly feeble (in fact so immeasurably small) that, even supposing them to reach the platinum, their heating-power would be an utterly vanishing quantity. Still mechanical considerations rendered the exclusion of *all* rays, of a higher refrangibility than those generated at the focus, necessary to the rigid solution of the problem. Hence, though the iodine employed in the foregoing experiments was sufficient to cut off the light of the sun at noon, I wished to submit its opacity to a severer test. The following experiments were accordingly executed.

A piece of thick black paper, mounted on a retort-ring, was caused gradually to approach the focus of obscure rays. The position of the focus was announced by the piercing of the paper; the combustion being quenched, the retort-ring was moved slightly nearer to the lamp, so that the converged beam passed through the burnt aperture, the focus falling about ½ an inch beyond. A bit of blackened platinum held immediately behind the aperture was raised to redness over a considerable space. The platinum was then moved to and fro until the maximum degree of incandescence was obtained, the point where this occurred being accurately marked. A cell containing a solution of alum was then placed between the diaphragm of black paper and the iodine-cell. The alum solution diminished materially the invisible radiation, but it was without sensible influence on such visible rays as the concentrated beam contained. All stray light issuing from the crevices in the lamp had been previously cut off, the daylight also being excluded from the room. The eye was then brought on a level with the aperture and slowly approximated to it, until the point which marked the focus was reached. A singular appearance presented itself. The incandescent coke points of the lamp were seen perfectly black, projected on a deep-red ground. When the points were moved up and down, their black images moved also. When brought into contact, a white space was seen at the extremities of the points, appearing to separate them. The points were seen erect. By careful observation the whole of the points could be seen, and even the holders which supported them. The black appearance of the incandescent portion of the points could of course only be relative; they intercepted more of the light reflected from the mirror behind than they could make good by their direct emission.

The solution of iodine, 1·2 inch in thickness, proving unequal to the severe test here applied to it, I had two other cells constructed—the one with transparent rock-salt sides, the other with glass ones. The width of the former was 2 inches, that of the latter nearly 2½ inches. Filled with the solution of iodine, these cells were placed in succession in front of the camera, and the concentrated beam was sent through them. Determining the focus as before, and afterwards introducing the alum-cell, the eye on being brought up to the focus received no impression of light. The alum-cell was then abandoned, and the undefended eye was caused to approach the focus: the heat was intolerable, but it seemed to affect the eyelids and not the retina. An aperture somewhat larger than the pupil being made in a metal screen, the eye was placed behind it, and brought slowly and cautiously up to the focus. The whole concentrated beam here entered the pupil; but no impression of light was produced, nor was the retina sensibly affected by the heat. The eye was then withdrawn, and a plate of platinized platinum was placed in the position occupied by the retina a moment before. It instantly rose to vivid redness*. The rays which produced this incandescence were certainly invisible ones, and the failure to obtain, with the most sensitive media and in the darkest room, the slightest evidence of fluorescence at the obscure focus, proved the invisible rays to be exclusively extra-red.

When intense effects are sought after, the problem is to collect as many of the invisible rays as possible, and to concentrate them on the smallest possible space. The nearer the mirror is to the source of rays, the more of these rays will it intercept and reflect, and the nearer the focus is to the same source, the smaller will the image be. To secure proximity both of focus and mirror, the latter must be of short focal length. If a mirror of long focal length be employed, its distance from the source of rays must be considerable to bring the focus near the source, but when placed at a distance, a great number of rays escape the mirror altogether. If, on the other hand, the mirror be too deep, spherical aberration comes into play; and though a vast quantity of rays may be collected, their convergence at the focus is imperfect. To determine the best form of mirror, I had three constructed: the first is 4·1 inches in diameter and of 1·4 inch focal length; the second 7·9 inches in diameter and of 3 inches focal length; the third 9 inches in diameter, with a focal length of 6 inches. Fractures caused by imperfect annealing repeatedly occurred; but at length I was so fortunate as to obtain the three mirrors, each

* I do not recommend the repetition of these experiments.

without a flaw. The most convenient distance of the focus from the source, I find to be about 5 inches; and the position of the mirror ought to be arranged accordingly. This distance permits of the introduction of an iodine-cell of sufficient depth, while the heat at the focus is exceedingly powerful.

The isolation of the luminiferous ether from the air is strikingly illustrated by these experiments. The air at the focus may be of a freezing temperature, while the ether possesses an amount of heat competent, if absorbed, to impart to that air the temperature of flame. An air-thermometer is unaffected where platinum is raised to a white heat. Numerous experiments will suggest themselves to every one who wishes to operate upon the invisible heat-rays. The dense volumes of smoke which rise from a blackened block of wood when it is placed in the dark focus are very striking: matches are of course at once ignited, and gunpowder instantly exploded. Dry black paper held there bursts into flame. Chips of wood are also inflamed: the dry wood of a hat-box is very suitable for this experiment. When a sheet of brown paper is placed a little beyond the focus, it is first brought to vivid incandescence over a large space; the paper then yields, and the combustion propagates itself as a burning ring round the centre of ignition. Charcoal is reduced to an ember at the focus, and disks of charred paper glow with extreme vividness. Sheet lead and tin, if blackened, may be fused, while a thick cake of fusible metal is quickly pierced and melted. Blackened zinc foil placed at the focus bursts into flame; and by drawing the foil slowly through the focus, its ignition may be kept up till the whole of the foil is consumed. Magnesium wire, flattened at the end and blackened, also bursts into vivid combustion. A cigar or a tobacco-pipe may of course be instantly lighted at the dark focus. The bodies experimented on may be enclosed in glass receivers, the concentrated rays will still burn them after having crossed the glass. A small chip of wood in a jar of oxygen bursts suddenly into flame; charcoal burns, while charcoal bark throws out suddenly showers of scintillations.

§ 6.

In all these cases the body exposed to the action of the invisible rays was more or less combustible. It required to be heated more or less to initiate the attack of the atmospheric oxygen. Its vividness was in great part due to combustion, and does not furnish a conclusive proof that the refrangibility of the incident rays was elevated. This, which is the result of greatest theoretic import, is effected by exposing non-combustible bodies at the focus, or by enclosing combustible ones in a space devoid of oxygen. Both in air and *in vacuo* platinized platinum foil has been repeatedly raised to a white heat. The same result has been obtained with a sheet of charcoal or coke suspended *in vacuo*. On looking at the white-hot platinum through a prism of bisulphide of carbon, a rich and complete spectrum was obtained. All the colours, from red to violet, glowed with extreme vividness. The waves from which these colours were primarily extracted had neither the visible nor the extra-violet rays commingled with them; they were exclusively extra-red. The action of the atoms of platinum, copper, silver, and carbon upon these rays transmutes them from heat-rays into light-rays. They impinge upon the platinum at a certain rate; they return from it at a quicker rate. Their refrangibility is thus raised, the invisible being rendered visible.

To express this transmutation of heat-rays into others of higher refrangibility, I would propose the term *calorescence*. It harmonizes well with the term "fluorescence" introduced by Professor STOKES, and is also suggestive of the character of the effects to which it is applied. The phrase "transmutation of rays," introduced by Professor CHALLIS*, covers both classes of effects.

§ 7.

In the foregoing section I have described arrangements made with a view of avoiding the danger incidental to the use of so inflammable a substance as the bisulphide of carbon. I have since thought of accomplishing this end in a simpler way, and thus facilitating the repetition of the experiments. The following arrangement (Plate I. fig. 6) may be adopted with safety.

A B C D is an outline of the camera.

x y the silvered mirror within it.

c the carbon points of the electric light.

o p the aperture in front of the camera, through which issues the beam reflected by the mirror *x y*.

Let the distance of the mirror from the carbon points be such as to render the reflected beam slightly convergent.

Fill an ordinary glass flask with the solution of iodine, and place the flask in the path of the reflected beam at a safe distance from the lamp. The flask acts as a lens and filter at the same time, the bright rays are intercepted, and the dark ones are powerfully converged. F, Plate I. fig. 6, represents such a flask; and at the focus formed a little beyond it combustion and calorescence may be produced.

The following results have been obtained with a series of flasks of different dimensions, at a distance of 3½ feet from the carbon points.

1. With a spherical flask, 6¾ inches in diameter: platinum was raised to redness at the focus, and black paper inflamed.

2. Ordinary Florence flask, 3¼ inches in diameter: platinum raised to bright redness over a large irregular space. Near the lamp, the effects obtained with this flask were very striking.

3. Small flask, 1·8 inch in diameter, not quite spherical: platinum rendered white-hot; paper immediately inflamed.

4. A still smaller flask, 1·5 inch in diameter: effects very good; about the same as the last.

5. The bulb of a pipette: effects striking, but not quite so brilliant as with the less regularly shaped small flasks.

---

* Philosophical Magazine, Ser. 4. vol. xii. p. 521.

It follows as a matter of course, that where platinum is raised to whiteness, the combustion of wood, charcoal, zinc, and magnesium may also be effected.

By the arrangement here described, platinum has been raised to redness at a distance of 22 feet from the source of the rays.

The best mirror, however, scatters the rays more or less; and by this scattering, the beam at a great distance from the lamp becomes much enfeebled. The effect in free air is intensified when the beam is caused to pass through a tube polished within, which prevents the lateral waste of radiant heat. Such a tube, placed in front of the camera, is represented at A B, fig. 7, Plate I. The flask may be held against its end by the hand, or it may be permanently fixed there. With a battery of fifty cells platinum may be raised to a white heat at the focus of the flask.

Again, instead of a flask filled with the opaque solution, let a glass or rock-salt lens (L, fig. 8, Plate I.), 2·5 inches wide, and having a focal length of 3 inches, be placed in the path of the reflected beam. The rays are converged; and at their point of convergence all the effects of calorescence and combustion may be obtained.

In this case the luminous rays are to be cut off by a cell ($m\,n$) with plane glass sides; it may be placed either before or behind the lens.

Finally, the arrangement shown in Plate I. fig. 9 may be adopted. The beam reflected by the mirror within the camera is received and converged by a second mirror, $x'\,y'$. At the point of convergence, which may be several feet from the camera, all the effects hitherto described may be obtained. The light of the beam may be cut off at any convenient point of its course; but in ordinary cases the experiment is best made by employing the bichloride instead of the bisulphide of carbon, and placing the cell ($m\,n$) containing the opaque solution close to the camera. The moment the coal points are ignited, explosion, combustion, or calorescence, as the case may be, occurs at the focus.

The ordinary lamp and camera of Duboscq may be employed in these experiments. With proper mirrors, which are easily procured, a series of effects which, I venture to affirm, will interest everybody who witnesses them may, with the greatest facility, be obtained.

It is also manifest that, save for experiments made in darkness, the camera is not necessary. The mirrors and filter may be associated with the naked lamp.

I have sought to *fuse* platinum with the invisible rays of the electric light, but hitherto without success. In some experiments I have employed a large model of Foucault's lamp, which permitted me to use a battery of 100 cells. In other experiments I employed two batteries, one of 100 cells and one of 70, making use of two lamps, two mirrors, and two filters, and converging the heat of both lamps in opposite directions upon the same point. When a leaf of platinum was placed at the common focus, the converged beams struck it at opposite sides, and raised it to dazzling whiteness. I am persuaded that the metal could be fused, if the platinum black upon its surface could be retained. But this was immediately dissipated by the intense heat, and, the reflecting power of the metal coming into play, the absorption was so much lowered that fusion was not effected. By coating the platinum with lampblack it has been brought to the verge of fusion, the incipient yielding of the mass being perfectly apparent after it had cooled. Here, however, as in the case of the platinized platinum, the absorbing substance disappears too quickly. Copper and aluminum, however, when thus treated, are speedily burnt up.

§ 8.

Thus far I have dealt exclusively with the invisible radiation of the electric light; but all solid bodies raised to incandescence emit these invisible calorific rays. The denser the incandescent body, moreover, the more powerful is its obscure radiation. We possess at the Royal Institution very dense cylinders of lime for the production of the Drummond light; and when a copious oxyhydrogen-flame is projected against one of them it shines with an intense yellowish light, while the obscure radiation is exceedingly powerful. Filtering the latter from the total emission by the solution of iodine, all the effects of combustion and calorescence described in the foregoing pages may be obtained at the focus of the invisible rays. The light obtained by projecting the oxyhydrogen-flame upon compressed magnesia, after the manner of Signor CARLEVARIS, is whiter than that emitted by our lime; but the substance being light and spongy, its obscure radiation is surpassed by that of our more solid cylinders*.

The invisible rays of the sun have also been transmuted. A concave mirror, 3 feet in diameter, was mounted on the roof of the Royal School of Mines in Jermyn Street. The focus was formed in a darkened chamber in which the platinized platinum foil was exposed. Cutting off the visible rays by the solution of iodine, feeble but distinct incandescence was there produced by the invisible rays.

A blackened tin tube (A B, fig. 10, Plate I.) with square cross section and open at one end, was furnished at the other with a plane mirror ($x y$) forming an angle of 45° with the axis of the tube. A lateral aperture ($x o$), about 2 inches square, was cut out in front of the mirror. Over this aperture was placed a leaf of platinized platinum. Turning the leaf towards the concave mirror, the concentrated sunbeams were permitted to fall upon it. In the glare of daylight it was quite impossible to see whether the platinum was incandescent or not; but placing the eye at B, the glow of the platinum could be seen by reflexion from the plane mirror. Incandescence was thus obtained at the focus of the large mirror, X Y, after the removal of the visible rays by the iodine solution, $m n$.

---

* The discovery of fluorescence by Professor STOKES naturally excited speculation as to the possibility of a change of refrangibility in the opposite direction. Mr. GROVE, I believe, made various experiments with a view to effect such a change; but very soon after the publication of Professor STOKES's Memoir Dr. MILLER pointed to the lime-light itself as an instance of raised refrangibility. From its inability to penetrate glass screens, he inferred that the radiation of the oxyhydrogen-flame was almost wholly extra-red, an inference the truth of which has been since established by direct prismatic analysis. The intense light produced by the oxyhydrogen-flame when projected upon lime must, he concluded, involve a change of period from slow to quick, or, in other words, a virtual elevation of refrangibility. (Elements of Chemistry, 1855, p. 210.)

To obtain a clearer sky, I had this mirror transferred to the garden of my friend Mr. Lubbock, near Chislehurst. The effects obtained with the total solar radiation were extraordinary. Large spaces of the platinum leaf, and even thick foil, when exposed at the focus, disappeared as if vaporized*. The handle of a pitchfork, similarly exposed, was soon burnt quite across. Paper placed at the focus burst into flame with almost explosive suddenness. The high ratio which the visible radiation of the sun bears to the invisible was strikingly manifested in these experiments. With a *total* radiation vastly inferior, the invisible rays of the electric light, or of the lime-light, raise platinum to whiteness, while, when the visible constituents of the concentrated sunbeam were intercepted, the most that could be obtained from the dark rays of the sun was a bright-red heat. The heat of the luminous rays is so great as to render it exceedingly difficult to experiment with the solution of iodine. It boiled up incessantly, exposure for two or three seconds being sufficient to raise it to ebullition. This high ratio of the luminous to the non-luminous radiation, is doubtless to be ascribed in part to the absorption of a large portion of the latter by the aqueous vapour of the air. From it, however, may also be inferred the enormous temperature of the sun.

Converging the sun's rays with a hollow lens filled with the solution of iodine, incandescence was obtained at the invisible focus of the lens on the roof of the Royal Institution.

Knowing the permeability of good glass to the solar rays, I requested Mr. Mayall to permit me to make a few experiments with his fine photographic lens at Brighton. Though exceedingly busy at the time, he in the kindest manner abandoned to my assistant, Mr. Barrett, the use of his apparatus for the three best hours of a bright summer's day. A red heat was obtained at the focus of the lens after the complete withdrawal of the luminous portion of the radiation.

§ 9.

Black paper has been very frequently employed in the foregoing experiments, the action of the invisible rays upon it being most energetic. This suggests that the absorption of those rays is not independent of colour. A red powder is red because of the entrance and absorption of the luminous rays of higher refrangibility than the red, and the ejection of the unabsorbed red light by reflexion at the limiting surfaces of the particles of the red body. This feebleness of absorption of the red rays extends to the rays of greater length beyond the red; and the consequence is that red paper when exposed at the focus of invisible rays is scarcely charred, when black paper bursts in a moment into flame. The following Table exhibits the condition of paper of various kinds when exposed at the dark focus of an electric light of moderate intensity.

---

* Concentrating the solar rays with a mirror 9 inches in diameter and of 6 inches focal length upon a leaf of platinized platinum, the metal was instantly pierced. Causing the focus to pass along the leaf, it was cut by the sunbeam, as if a sharp instrument had been drawn along it.

Paper.	Condition.
Glazed orange-coloured paper .	Barely charred.
,, red- ,, .	Scarcely tinged; less than the orange.
,, green- ,, .	Pierced with a small burning ring.
,, blue- ,, .	The same as the last.
,, black- ,, .	Pierced; and immediately set ablaze.
,, white- ,, .	Charred; not pierced.
Thin foreign-post	Barely charred; less than the white.
Foolscap	Still less charred; about the same as the orange.
Thin white blotting-paper . .	Scarcely tinged.
,, whitey-brown ,, . .	The same; a good deal of heat seems to get through these two last papers.
Ordinary brown ,, . .	Pierced immediately, a beautiful burning ring expanding on all sides.
Thick brown ,, . .	Pierced, not so good as the last.
Thick white sand-paper . .	Pierced with a burning ring.
Brown emery ,, . .	The same as the last.
Dead-black ,, . .	Pierced, and immediately set ablaze.

We have here an almost total absence of absorption on the part of the red paper. Even white absorbs more, and is consequently more easily charred. Rubbing the red iodide of mercury over paper, and exposing the reddened surface at the focus, a thermograph of the coal points is obtained, which shows itself by the discharge of the colour at the place on which the invisible image falls. Expecting that this change of colour would be immediate, I was at first surprised at the time necessary to produce it. We are here reminded of FRANKLIN'S experiments on cloths of different colours, and his conclusion that dark colours are the best absorbers. This conclusion, however, might readily be pushed too far. FRANKLIN'S colours were of a special kind, and their deportment by no means warrants a general conclusion. The invisible rays of the sun possess, according to MÜLLER, twice the energy of the visible ones. A white substance may absorb the former, while a dark substance—dark because of its absorption of the feeblest portion of the radiation—may not do so. The white powder of alum and the dark powder of iodine, exposed to the action of a source in which the invisible rays greatly surpass the visible in calorific power, exhibit a deportment at direct variance with the popular notion that dark colours are the best absorbers.

§ 10.

In conclusion, I would briefly refer to a few experiments made to determine the calorescence obtainable through glasses of various colours. In the first column of the subjoined Table the colour of the glass is given; in the second column the effect observed when a brilliant spectrum was regarded through the glass is stated; and in the third column the appearance of a leaf of platinized platinum when placed at the focus, after the converged beam had passed through the glass, is mentioned.

Colour of glass.	Prismatic examination.	Calorescence.
Dark red	Red only transmitted	Dull white heat.
Mean red	Red only transmitted	White heat.
Light red	Yellow intercepted with greatest power	Bright white.
Yellow	All the blue end absorbed	Vivid red with bright yellow in centre.
Green	Besides the green, a dull red fringe and a blue band were transmitted	No incandescence.
Dark purple	Extreme blue and red transmitted	Vivid orange.
Mean purple	Central portion of spectrum cut out	Vivid orange.
Light purple	Dims the whole spectrum, but chiefly absorbs the green	Vivid orange.
Dark blue	Transmits the blue, a green band, and a band in the extreme red	Red heat.
Mean blue	Blue; a yellowish-green band and the extreme red transmitted	Reddish-pink heat.
Light blue	Transmits a series of bands—blue and green, a red band next orange, then a dark-red band, and finally extreme red	Pink heat, passing into red.
Another blue glass		Pink heat.
Black glass No. 1	Dims all the spectrum: white light transmitted	Barely visible red.
Black glass No. 2	Whitish-green light transmitted	Dull red.
Black glass No. 3	Deep-red light transmitted	Bright red, orange in the middle.

The extremely remarkable fact here reveals itself, that when the beam of the electric lamp is sifted by certain blue glasses, the platinum at the focus glows with a distinct pink colour. Every care was taken to avoid subjective illusion here. The pink colour was also obtained at the focus of invisible rays. Withdrawing all the glasses, and filtering the beam by a solution of iodine alone, platinum was raised nearly to whiteness at the focus. On introducing the pale-blue glass between the iodine cell and the focus, the calorescence of the platinum was greatly enfeebled—so much so, that a darkened room was necessary to bring it out in full distinctness; when seen, however, the thermograph was pink. A disk of carbonized paper being exposed at the obscure focus, rose at once to vivid whiteness when the blue glass was absent; but when present, the colour of the light emitted by the carbon was first a distinct pink; the attack of the atmospheric oxygen soon changes this colour, the combustion of the carbon extending on all sides as a white-hot circle. If subsequent experiments should confirm this result, it would follow that there is a gap in the calorescence, the atoms of the platinum vibrating in red and blue periods, and not in intermediate ones. But I wish here to say that further experiments, which I hope shortly to make, are necessary to satisfy my own mind as to the cause of this phenomenon.

The incandescent thermograph of the coal points being obtained, a very light-red glass introduced between the opaque solution and the platinum reduced the thermograph both in size and brilliancy. A second red glass, of deeper colour, rendered the thermograph still smaller and feebler. A dark-red glass reduced it still more—the visible surface being in this case extremely minute, and the heat a dull red merely. When, instead of the coloured glass, a sheet of pure-white glass was introduced, the image of the coal points stamped upon the platinum foil was scarcely diminished in brilliancy. A thick piece of glass of deep ruby-red proved equally transparent; its introduction scarcely changed the vividness of the thermograph. The colouring-matter in this instance was the *element* gold, not the compound suboxide of copper employed in the other red glasses. Many specimens of gold jelly, prepared by Mr. FARADAY for his investigation of the colours of gold, though of a depth approaching to absolute blackness, showed themselves eminently transparent to the obscure heat-rays; their introduction scarcely dimmed the brilliancy of the thermograph. Hence it would appear that even the metals themselves, in certain states of aggregation, share that high diathermic power which the elementary metalloids have been found to display.

I have just said that a sheet of pure-white glass, when interposed in the path of the condensed invisible beam, scarcely dimmed the brilliancy of the thermograph. The intense calorific rays of the electric light pass through such glass with freedom. We here come to a point of considerable practical importance to meteorologists. When such pure-white glass has carbon mixed with it when in a molten condition, the resulting black glass is still eminently transparent to those invisible heat-rays which constitute the greater part of the sun's radiation. I have pieces of glass, to all appearance black, which transmit 63 per cent. of the total heat of the electric light; and there is not the slightest doubt that, in thicknesses sufficient to quench entirely the light of the sun, such glass would transmit a large portion of his invisible heat-rays. This is the glass often, if not uniformly, employed in the construction of our black-bulb thermometers, under the impression that the blackening secures the entire absorption of the solar rays. This conclusion is fallacious, and the instruments are correspondingly defective. A large portion of the sun's rays pass through such black glass, impinge upon the mercury within the bulb, and are ejected by reflexion. Such rays contribute nothing to the heating of the thermometer.

When a sheet of common window-glass, apparently transparent, was placed between the iodine solution and the platinum leaf at the focus, the thermograph was more dimmed than by the black glass last referred to. The window-glass here employed, when looked at edgeways, was green; and this experiment proves how powerfully this green colouring-matter, even in infinitesimal quantity, absorbs the invisible heat-rays.

Perfect imperviousness might doubtless be secured by augmenting the quantity of green colouring-matter. It is with glass of this description that the carbon should be mixed in the construction of black-bulb thermometers; on entering such glass the solar rays would be entirely absorbed, and greater differences than those now observed would probably be found to exist between the black-bulb and the ordinary thermometer.

In conclusion, it gives me pleasure to mention the intelligence and skill displayed by my assistant, Mr. BARRETT, in executing the numerous experiments committed to his care during the progress of this investigation.

II. *A Supplementary Memoir on the Theory of Matrices.*

By A. Cayley, *Esq., F.R.S.*

Received October 24,—Read December 7, 1865.

M. Hermite, in a paper "Sur la théorie de la transformation des fonctions Abéliennes," Comptes Rendus, t. xl. (1855), pp. 249, &c., establishes incidentally the properties of the matrix for the automorphic linear transformation of the bipartite quadric function $xw'+yz'-zy'-wx'$, or transformation of this function into one of the like form, $XW'+YZ'-ZY'-WX'$. These properties are (as will be shown) deducible from a general formula in my "Memoir on the Automorphic Linear Transformation of a Bipartite Quadric Function," Phil. Trans. vol. cxlviii. (1858), pp. 39–46; but the particular case in question is an extremely interesting one, the theory whereof is worthy of an independent investigation. For convenience the number of variables is taken to be *four*; but it will be at once seen that as well the demonstrations as the results are in fact applicable to any *even* number whatever of variables.

Article Nos. 1 & 2.—*Notation and Remarks.*

1. I use throughout the notation and formulæ contained in my "Memoir on the Theory of Matrices," Phil. Trans. vol. cxlviii. (1858), pp. 17–37, and in the above-mentioned memoir on the Automorphic Transformation. With respect to the composition of matrices, the rule of composition is as follows, viz., any *line* of the compound matrix is obtained by combining the corresponding *line* of the first or further component matrix with the several *columns* of the second or nearer component matrix; it is very convenient to indicate this by the algorithm,

$$\left(\begin{array}{c} a\,,\ b\,,\ c \\ a',\ b',\ c' \\ a'',\ b'',\ c'' \end{array}\right| \between \left|\begin{array}{c} \alpha\,,\ \beta\,,\ \gamma \\ \alpha',\ \beta',\ \gamma' \\ \alpha'',\ \beta'',\ \gamma'' \end{array}\right) = \begin{array}{c|ccc} & (\alpha, \alpha', \alpha''), & (\beta, \beta', \beta''), & (\gamma, \gamma', \gamma'') \\ \hline (a\,,\ b\,,\ c) & ,, & ,, & ,, \\ (a', b', c') & ,, & ,, & ,, \\ (a'', b'', c'') & ,, & ,, & ,, \end{array}$$

which exhibits very clearly the terms which are to be combined together; thus in the upper left-hand corner we have $(a, b, c \between \alpha, \alpha', \alpha'')$, and so for the other places in the compound matrix.

2. It is not in the Memoir on Matrices explicitly remarked, but it is easy to see that sums of matrices, all the matrices being of the same order, may be multiplied together by the ordinary rule; thus

$$(A+B)(C+D)=AC+AD+BC+BD:$$

this remark will be useful in the sequel.

Article Nos. 3 to 13.—*First Investigation.*

3. We have to consider the formulæ for the automorphic linear transformation of the function $xw'+yz'-zy'-wx'$, that is, of the function

$$\left(\begin{array}{cccc} \cdot, & \cdot, & \cdot, & -1 \\ \cdot, & \cdot, & -1, & \cdot \\ \cdot, & 1, & \cdot, & \cdot \\ 1, & \cdot, & \cdot, & \cdot \end{array}\right)(x, y, z, w)(x', y', z', w')$$

$$=(\Omega)(x, y, z, w)(x', y', z', w'),$$

viz., if the variables are transformed by the formulæ

$$(x, y, z, w)=(\Pi)(X, Y, Z, W),$$
$$(x', y', z', w')=(\Pi)(X', Y', Z', W'),$$

then the matrix (Π) is such that we have identically

$$(\Omega)(x, y, z, w)(x', y', z', w')=(\Omega)(X, Y, Z, W)(X', Y', Z', W');$$

the expression for (Π) is given in my memoir above referred to; viz., observing that the matrix (Ω) is skew symmetrical, then (No. 13) we have

$$\Pi=\Omega^{-1}(\Omega-\Upsilon)(\Omega+\Upsilon)^{-1}\Omega,$$

where Υ is an arbitrary symmetrical matrix.

4. I propose to compare with the matrix Π the inverse matrix Π^{-1}. Recollecting that in the theory of matrices $(ABCD)^{-1}=D^{-1}C^{-1}B^{-1}A^{-1}$, we have

$$\Pi^{-1}=\Omega^{-1}(\Omega+\Upsilon)(\Omega-\Upsilon)^{-1}\Omega;$$

and it is to be shown that Π and Π^{-1} are composed of terms which (except as to their signs) are the same in each, so that either of these matrices is derivable from the other by a peculiar form of transposition. It is to be borne in mind throughout that Υ is symmetrical, Ω skew symmetrical.

5. I write for greater convenience

$$-\Pi\ \ =\Omega^{-1}(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}\Omega,$$
$$-\Pi^{-1}=\Omega^{-1}(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}\Omega,$$

and I compare in the first instance the matrices $(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}$ and $(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}$.

6. Any matrix whatever, and therefore the matrix $(\Upsilon+\Omega)^{-1}$, may be exhibited as the sum of a symmetrical matrix and a skew symmetrical matrix; that is, we may write

$$(\Upsilon+\Omega)^{-1}=\Upsilon'+\Omega',$$

where Υ' is symmetrical, Ω' is skew symmetrical. We have then

$$(\Upsilon+\Omega)(\Upsilon+\Omega)^{-1}=(\Upsilon+\Omega)(\Upsilon'+\Omega')=1,$$

where, here and in what follows, 1 denotes the matrix unity. Moreover

$$\Upsilon-\Omega=\text{tr.}(\Upsilon+\Omega),$$

and thence

$$(\Upsilon-\Omega)^{-1}=\big(\text{tr.}(\Upsilon+\Omega)\big)^{-1}=\text{tr.}(\Upsilon+\Omega)^{-1}=\text{tr.}(\Upsilon'+\Omega')=\Upsilon'-\Omega';$$

that is,

$$(\Upsilon-\Omega)^{-1}=\Upsilon'-\Omega';$$

and thence also

$$(\Upsilon-\Omega)(\Upsilon-\Omega)^{-1}=(\Upsilon-\Omega)(\Upsilon'-\Omega')=1.$$

We have therefore

$$(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}=(\Upsilon+\Omega-2\Omega)(\Upsilon'+\Omega')=1-2\Omega(\Upsilon'+\Omega'),$$

$$(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}=(\Upsilon-\Omega+2\Omega)(\Upsilon'-\Omega')=1+2\Omega(\Upsilon'-\Omega').$$

7. Suppose for a moment that

$$\Upsilon'+\Omega'=\left(\begin{array}{cccc} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{array}\right)$$

and therefore

$$\Upsilon'-\Omega'=\left(\begin{array}{cccc} a, & e, & i, & m \\ b, & f, & j, & n \\ c, & g, & k, & o \\ d, & h, & l, & p \end{array}\right)$$

8. We have

$$-\Omega(\Upsilon'+\Omega')=\left(\begin{array}{cccc} . & . & . & 1 \\ . & . & 1 & . \\ . & -1 & . & . \\ -1 & . & . & . \end{array}\right)\left(\begin{array}{cccc} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{array}\right)$$

$$=\begin{array}{l|cccc} & (a,e,i,m), & (b,f,j,n), & (c,g,k,o), & (d,h,l,p) \\ \hline (\;.\;\;.\;\;.\;\;1\;) & '' & '' & '' & '' \\ (\;.\;\;.\;\;1\;\;.\;) & '' & '' & '' & '' \\ (\;.\;\;-1\;\;.\;\;.\;) & '' & '' & '' & '' \\ (-1\;\;.\;\;.\;\;.\;) & '' & '' & '' & '' \end{array}$$

$$=\left(\begin{array}{cccc} m, & n, & o, & p \\ i, & j, & k, & l \\ -e, & -f, & -g, & -h \\ -a, & -b, & -c, & -d \end{array}\right).$$

9. And similarly,

$$\Omega(\Upsilon'-\Omega')=\left(\begin{array}{cccc} . & . & . & -1 \\ . & . & -1 & . \\ . & 1 & . & . \\ 1 & . & . & . \end{array}\right)\left(\begin{array}{cccc} a, & e, & i, & m \\ b, & f, & j, & n \\ c, & g, & k, & o \\ d, & h, & l, & p \end{array}\right)$$

$$\begin{array}{l|cccc} & (a,b,c,d), & (e,f,g,h), & (i,j,k,l), & (m,n,o,p) \\ \hline =(\ .\ \ .\ \ .\ -1\ ) & ,, & ,, & ,, & ,, \\ \ \ (\ .\ \ .\ -1\ \ .\ ) & ,, & ,, & ,, & ,, \\ \ \ (\ .\ \ 1\ \ .\ \ .\ ) & ,, & ,, & ,, & ,, \\ \ \ (\ 1\ \ .\ \ .\ \ .\ ) & ,, & ,, & ,, & ,, \end{array}$$

$$=\left(\begin{array}{cccc} -d, & -h, & -l, & -p \\ -c, & -g, & -k, & -o \\ b, & f, & j, & n \\ a, & e, & i, & m \end{array}\right).$$

10. Hence also

$$(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}=\left(\begin{array}{cccc} 1+2m, & 2n, & 2o, & 2p \\ 2i\ , & 1+2j, & 2k, & 2l \\ -2e\ , & -2f, & 1-2g, & -2h \\ -2a\ , & -2b, & -2c, & 1-2d \end{array}\right),$$

and

$$(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}=\left(\begin{array}{cccc} 1-2d, & -2h, & -2l\ , & -2p \\ -2c, & 1-2g, & -2k, & -2o \\ 2b, & 2f, & 1+2j\ , & 2n \\ 2a, & 2e, & 2i\ , & 1+2m \end{array}\right),$$

so that these matrices are composed of terms which, except as to the signs, are the same in each.

11. Now in general if

$$\Theta=\left(\begin{array}{cccc} \alpha\ , & \beta\ , & \gamma\ , & \delta \\ \alpha'\ , & \beta'\ , & \gamma'\ , & \delta' \\ \alpha'', & \beta'', & \gamma'', & \delta'' \\ \alpha''', & \beta''', & \gamma''', & \delta''' \end{array}\right),$$

then it is easy to see that

$$\Omega^{-1}\Theta\Omega=\left(\begin{array}{cccc} \delta''', & \gamma''', & -\beta''', & -\alpha''' \\ \delta'', & \gamma'', & -\beta'', & -\alpha'' \\ -\delta'\ , & -\gamma'\ , & \beta'\ , & \alpha' \\ -\delta\ , & -\gamma\ , & \beta\ , & \alpha \end{array}\right),$$

and hence, from the foregoing values of $(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}$ and $(\Upsilon+\Omega)(\Omega-\Upsilon)^{-1}$, we find

$$\Pi=-\Omega^{-1}(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}\Omega=\begin{pmatrix} -1+2d, & 2c, & -2b, & -2a \\ 2h, & -1+2g, & -2f, & -2e \\ 2l, & 2k, & -1-2j, & -2i \\ 2p, & 2o, & -2n, & -1-2m \end{pmatrix}$$

and

$$\Pi^{-1}=-\Omega^{-1}(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}\Omega=\begin{pmatrix} -1-2m, & -2i, & 2e, & 2a \\ -2n, & -1-2j, & 2f, & 2b \\ -2o, & -2k, & -1+2g, & 2c \\ -2p, & -2l, & +2h, & -1+2d \end{pmatrix}$$

which shows that the matrix Π for the automorphic transformation of the function $xw'+yz'-zy'-wx'$ is such that writing

$$\Pi=\begin{pmatrix} \mathrm{A}, & \mathrm{B}, & \mathrm{C}, & \mathrm{D} \\ \mathrm{E}, & \mathrm{F}, & \mathrm{G}, & \mathrm{H} \\ \mathrm{I}, & \mathrm{J}, & \mathrm{K}, & \mathrm{L} \\ \mathrm{M}, & \mathrm{N}, & \mathrm{O}, & \mathrm{P} \end{pmatrix} \text{ we have } \Pi^{-1}=\begin{pmatrix} \mathrm{P}, & \mathrm{L}, & -\mathrm{H}, & -\mathrm{D} \\ \mathrm{O}, & \mathrm{K}, & -\mathrm{G}, & -\mathrm{C} \\ -\mathrm{N}, & -\mathrm{J}, & \mathrm{F}, & \mathrm{B} \\ -\mathrm{M}, & -\mathrm{I}, & \mathrm{E}, & \mathrm{A} \end{pmatrix}$$

which is the theorem in question.

12. I remark in reference to the foregoing proof that writing

$$\Upsilon=\begin{pmatrix} a, & h, & g, & l \\ h, & b, & f, & m \\ g, & f, & c, & n \\ l, & m, & n, & p \end{pmatrix}$$

then the actual value of

$$(\Upsilon+\Omega)^{-1}, =\begin{pmatrix} a & , h & , g & , l-1 \\ h & , b & , f-1, & m \\ g & , f+1, & c & , n \\ l+1, & m & , n & , d \end{pmatrix}^{-1}$$

is

$$=\frac{1}{\Delta}\begin{pmatrix} \mathrm{A}+d & , \mathrm{H}+n+\nu, & \mathrm{G}-m-\mu, & \mathrm{L}-l+\varrho \\ \mathrm{H}+n-\nu, & \mathrm{B}+c & , \mathrm{F}-f+\lambda, & \mathrm{M}-g+\sigma \\ \mathrm{G}-m+\mu, & \mathrm{F}-f-\lambda, & \mathrm{C}+b & , \mathrm{N}+h+\tau \\ \mathrm{L}-l-\varrho & , \mathrm{M}-g-\sigma, & \mathrm{N}+h-\tau, & \mathrm{D}+a \end{pmatrix}$$

where

$$\begin{pmatrix} \mathrm{A}, & \mathrm{H}, & \mathrm{G}, & \mathrm{L} \\ \mathrm{H}, & \mathrm{B}, & \mathrm{F}, & \mathrm{M} \\ \mathrm{G}, & \mathrm{F}, & \mathrm{C}, & \mathrm{N} \\ \mathrm{L}, & \mathrm{M}, & \mathrm{N}, & \mathrm{D} \end{pmatrix}$$

is the matrix formed with the first minors of

$$\begin{pmatrix} a, & h, & g, & l \\ h, & b, & f, & m \\ g, & f, & c, & n \\ l, & m, & n, & d \end{pmatrix};$$

moreover

$$\begin{aligned} \lambda &= ad-l^2+nh-mg+1, & \varrho &= bc-f^2+nh-mg+1, \\ \mu &= bn-mf+dh-ml\quad, & \sigma &= fg-ch+gl-na\quad, \\ \nu &= dg-nl+nf-cm\quad, & \tau &= hf-bg+ma-lh\quad, \end{aligned}$$

and Δ is the determinant

$$\begin{pmatrix} a & , h & , g & , l+1 \\ h & , b & , f+1, & m \\ g & , f-1, & c & , n \\ l-1, & m & , n & , d \end{pmatrix}$$

viz., this is

$$=\begin{vmatrix} a, & h, & g, & l \\ h, & b, & f, & m \\ g, & f, & c, & n \\ l, & m, & n, & d \end{vmatrix} +ad-l^2+bc-f^2+2(nh-mg)+1.$$

13. The expression for $(\Upsilon-\Omega)^{-1}$ is obtained from that of $(\Upsilon+\Omega)^{-1}$ by merely transposing the terms of the matrix, or, what is the same thing, by changing the signs of λ, μ, ν, ϱ, σ, τ. And it would be easy by means of these developed values to verify the foregoing comparison of $(\Upsilon-\Omega)(\Upsilon+\Omega)^{-1}$ and $(\Upsilon+\Omega)(\Upsilon-\Omega)^{-1}$.

Article Nos. 14 to 22.—*Second Investigation.*

14. I consider from a different point of view the theory of a matrix

$$\Pi=\begin{pmatrix} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{pmatrix} \text{ such that } \Pi^{-1}=\begin{pmatrix} p, & l, & -h, & -d \\ o, & k, & -g, & -c \\ -n, & -j, & f, & b \\ -m, & -i, & e, & a \end{pmatrix},$$

or, as we may call it, a Hermitian matrix.

15. *Lemma.* The determinant

$$\nabla = \begin{vmatrix} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{vmatrix}$$

may be expressed, and that in two different ways, as a Pfaffian.

16. In fact multiplying the determinant into itself thus,

$$\nabla^2 = \begin{vmatrix} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{vmatrix} \text{ tr. } \begin{vmatrix} d, & c, & -b, & -a \\ h, & g, & -f, & -e \\ l, & k, & -j, & -i \\ p, & o, & -n, & -m \end{vmatrix}$$

we find

$$\nabla^2 = \begin{array}{c|cccc|} & (d,\ c,\ -b,\ -a), & (h,\ g,\ -f,\ -e), & (l,\ k,\ -j,\ -i), & (p,\ o,\ -n,\ -m) \\ \hline (a,\ b,\ c,\ d) & ,, & ,, & ,, & ,, \\ (e,\ f,\ g,\ h) & ,, & ,, & ,, & ,, \\ (i,\ j,\ k,\ l) & ,, & ,, & ,, & ,, \\ (m,\ n,\ o,\ p) & ,, & ,, & ,, & ,, \end{array} = \begin{vmatrix} s_{11}, & s_{12}, & s_{13}, & s_{14} \\ s_{21}, & s_{22}, & s_{23}, & s_{24} \\ s_{31}, & s_{32}, & s_{33}, & s_{34} \\ s_{41}, & s_{42}, & s_{43}, & s_{44} \end{vmatrix},$$

viz. we have $s_{11}=(a, b, c, d)(d, c, -b, -a)$, $s_{12}=(a, b, c, d)(h, g, -f, -e)$, &c.: we see at once that $s_{11}=0$, $s_{12}+s_{21}=0$, &c., viz. the determinant in s is a skew determinant, that is, the square of a Pfaffian. We have therefore

$$\nabla^2=(s_{12}\,s_{34}+s_{13}\,s_{42}+s_{14}\,s_{23})^2,$$

or extracting the square root of each side, and determining the sign by a comparison of any single term, we have

$$\nabla=s_{12}\,s_{34}+s_{13}\,s_{42}+s_{14}\,s_{23},$$

which is one of the required forms of ∇.

17. And in the same manner

$$\nabla^2 = \text{ tr. } \begin{vmatrix} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{vmatrix} \cdot \begin{vmatrix} m, & n, & o, & p \\ i, & j, & k, & l \\ -e, & -f, & -g, & -h \\ -a, & -b, & -c, & -d \end{vmatrix}$$

which is equal to the determinant

$$\begin{vmatrix} t_{11}, & t_{12}, & t_{13}, & t_{14} \\ t_{21}, & t_{22}, & t_{23}, & t_{24} \\ t_{31}, & t_{32}, & t_{33}, & t_{34} \\ t_{41}, & t_{42}, & t_{43}, & t_{44} \end{vmatrix} = \begin{array}{c|cccc} & (m,\ i,\ -e,\ -a), & (n,\ j,\ -f,\ -b), & (o,\ k,\ -g,\ -c), & (p,\ l,\ -h,\ -d) \\ \hline (a,\ e,\ i,\ m) & ,, & ,, & ,, & ,, \\ (b,\ f,\ j,\ n) & ,, & ,, & ,, & ,, \\ (c,\ g,\ k,\ o) & ,, & ,, & ,, & ,, \\ (d,\ h,\ l,\ p) & ,, & ,, & ,, & ,, \end{array}$$

viz. $t_{11}=(a, e, i, m)(m, i, -e, -a)$, &c.; this is likewise a skew determinant, and we have

$$\nabla^2=(t_{12}t_{34}+t_{13}t_{24}+t_{14}t_{23})^2,$$

or extracting the square root of each side, and determining the sign by the comparison of any single term, we have

$$\nabla=t_{12}t_{34}+t_{13}t_{24}+t_{14}t_{23},$$

which is the other of the required forms of ∇.

18. Consider now the matrix

$$\left(\begin{array}{cccc} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{array}\right)$$

which is such that

$$\left(\begin{array}{cccc} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{array}\right)^{-1}=\left(\begin{array}{cccc} p, & l, & -h, & -d \\ o, & k, & -g, & -c \\ -n, & -j, & f, & b \\ -m, & -i, & e, & a \end{array}\right)$$

this gives

$$\left(\begin{array}{cccc} 1, & 0, & 0, & 0 \\ 0, & 1, & 0, & 0 \\ 0, & 0, & 1, & 0 \\ 0, & 0, & 0, & 1 \end{array}\right)=\left(\begin{array}{cccc} a, & b, & c, & d \\ e, & f, & g, & h \\ i, & j, & k, & l \\ m, & n, & o, & p \end{array}\right)\left(\begin{array}{cccc} p, & l, & -h, & -d \\ o, & k, & -g, & -c \\ -n, & -j, & f, & b \\ -m, & -i, & e, & a \end{array}\right)$$

$$\begin{array}{r|cccc} & (p, o, -n, -m), & (l, k, -j, -i), & (-h, -g, f, e), & (-d, -c, b, a \\ \hline =(a, b, c, d) & '' & '' & '' & '' \\ (e, f, g, h) & '' & '' & '' & '' \\ (i, j, k, l) & '' & '' & '' & '' \\ (m, n, o, p) & '' & '' & '' & '' \end{array}$$

which is in fact

$$\left(\begin{array}{cccc} 1, & 0, & 0, & 0 \\ 0, & 1, & 0, & 0 \\ 0, & 0, & 1, & 0 \\ 0, & 0, & 0, & 1 \end{array}\right)=\left(\begin{array}{cccc} s_{14}, & s_{13}, & -s_{12}, & -s_{11} \\ s_{24}, & s_{23}, & -s_{22}, & -s_{21} \\ s_{34}, & s_{33}, & -s_{32}, & -s_{31} \\ s_{44}, & s_{43}, & -s_{42}, & -s_{41} \end{array}\right),$$

and the two matrices will be equal, term by term, if only

$$1=s_{14}=s_{23},$$

$$0=s_{13}=s_{12}=s_{24}=s_{34},$$

that is, if six conditions are satisfied.

19. But we have also (a matrix and its reciprocal being convertible)

$$\begin{pmatrix}1, & 0, & 0, & 0\\ 0, & 1, & 0, & 0\\ 0, & 0, & 1, & 0\\ 0, & 0, & 0, & 1\end{pmatrix}=\begin{pmatrix}p\,, & l\,, & -h, & -d\\ o\,, & k, & -g, & -c\\ -n\,, & -j\,, & f, & b\\ -m, & -i, & e, & a\end{pmatrix}\begin{pmatrix}a\,, & b, & c, & d\\ e\,, & f, & g, & h\\ i\,, & j, & k, & l\\ m, & n, & o, & p\end{pmatrix}$$

$$=\begin{array}{c|cccc} & (a,e,i,m), & (b,f,j,n), & (c,g,k,o), & (d,h,l,p)\\ \hline (\;p\,,\;\; l\,,\; -h,\; -d) & '' & '' & '' & ''\\ (\;o\,,\;\; k,\; -g,\; -c) & '' & '' & '' & ''\\ (-n\,,\; -j\,,\;\; f,\;\; b) & '' & '' & '' & ''\\ (-m,\; -i,\;\; e,\;\; a) & '' & '' & '' & '' \end{array}$$

which is in fact

$$\begin{pmatrix}1, & 0, & 0, & 0\\ 0, & 1, & 0, & 0\\ 0, & 0, & 1, & 0\\ 0, & 0, & 0, & 1\end{pmatrix}=\begin{pmatrix}t_{14}, & t_{24}, & t_{34}, & t_{44}\\ t_{13}, & t_{23}, & t_{33}, & t_{43}\\ -t_{12}, & -t_{22}, & -t_{32}, & -t_{42}\\ -t_{11}, & -t_{21}, & -t_{31}, & -t_{41}\end{pmatrix}$$

and we obtain for the equality of the two matrices the six conditions

$$1=t_{14}=t_{23},\quad 0=t_{13}=t_{12}=t_{24}=t_{34},$$

equivalent to the former set of six conditions.

20. We obtain from either set of conditions, for the determinant the value

$$\nabla=\begin{vmatrix}a\,, & b, & c, & d\\ e\,, & f, & g, & h\\ i\,, & j, & k, & l\\ m, & n, & o, & p\end{vmatrix}=\varkappa^2.$$

21. Write

$$(x,y,z,w)=\begin{pmatrix}a\,, & b, & c, & d\\ e\,, & f, & g, & h\\ i\,, & j\,, & k, & l\\ m, & n, & o, & p\end{pmatrix})(X,Y,Z,W)\,;\quad (x',y',z',w')=\begin{pmatrix}a\,, & b, & c, & d\\ e\,, & f, & g, & h\\ i\,, & j\,, & k, & l\\ m, & n, & o, & p\end{pmatrix})(X',Y',Z',W'),$$

then substituting for $(x, y, z, w)(x', y', z', w')$ their values, we find

$$xw'+yz'-zy'-wx'=-\begin{pmatrix}t_{11}, & t_{12}, & t_{13}, & t_{14}\\ t_{21}, & t_{22}, & t_{23}, & t_{24}\\ t_{31}, & t_{32}, & t_{33}, & t_{34}\\ t_{41}, & t_{42}, & t_{43}, & t_{44}\end{pmatrix})(X,Y,Z,W)(X',Y',Z',W')$$

$$=\left(\begin{array}{cccc} . & . & . & -1 \\ . & . & -1 & . \\ . & 1 & . & . \\ 1 & . & . & . \end{array}\right)\!\between\!(\mathrm{X}, \mathrm{Y}, \mathrm{Z}, \mathrm{W})\!\between\!(\mathrm{X}', \mathrm{Y}', \mathrm{Z}', \mathrm{W}')$$

$$=\mathrm{XW}'+\mathrm{YZ}'-\mathrm{ZY}'-\mathrm{WX}';$$

and similarly writing

$$(\mathrm{X}, \mathrm{Y}, \mathrm{Z}, \mathrm{W})=\left(\begin{array}{cccc} p, & l, & -h, & -d \\ o, & k, & -g, & -c \\ -n, & -j, & f, & b \\ -m, & -i, & e, & a \end{array}\right)\!\between\!(x, y, z, w),\quad (\mathrm{X}', \mathrm{Y}', \mathrm{Z}', \mathrm{W}')=\left(\begin{array}{cccc} p, & l, & -h, & -d \\ o, & k, & -g, & -c \\ -n, & -j, & f, & b \\ -m, & -i, & e, & a \end{array}\right)\!\between\!(x', y', z', w'),$$

we obtain with the s coefficients the equivalent result,

$$\mathrm{XW}'+\mathrm{YZ}'-\mathrm{ZY}'-\mathrm{WX}'=xw'+yz'-zy'-wx'.$$

We thus see conversely that the Hermitian matrix is in fact the matrix for the automorphic transformation of the function $xw'+yz'-zy'-wx'$.

22. Considering any two or more matrices for the automorphic transformation of such a function, the matrix compounded of these is a matrix for the automorphic transformation of the function—or, theorem, the matrix compounded of two or more Hermitian matrices is itself Hermitian.

Article No. 23.—*Theorem on a Form of Matrices.*

23. I take the opportunity of mentioning a theorem relating to the matrices which present themselves in the arithmetical theory of the composition of quadratic forms. Writing

$$(\mathrm{X})=\left(\begin{array}{cccc} . , & \alpha , & a , & b+\beta \\ -\alpha , & . , & b-\beta, & c \\ -a , & -(b-\beta), & . , & \gamma \\ -(b+\beta), & -c , & -\gamma , & . \end{array}\right) \text{ and } \therefore\ (\mathrm{X})^{-1}=\frac{1}{\mathrm{D}-\Delta}\left(\begin{array}{cccc} . , & \gamma , & -c , & b-\beta \\ -\gamma , & . , & b+\beta, & -a \\ c , & -(b+\beta), & . , & \alpha \\ -(b-\beta), & a , & -\alpha , & . \end{array}\right)$$

where $\mathrm{D}=ac-b^2$, $\Delta=\alpha\gamma-\beta^2$; and similarly,

$$\mathrm{X}'=\left(\begin{array}{cccc} . , & \alpha' , & a' , & b'+\beta' \\ -\alpha' , & . , & b'-\beta', & c' \\ -a' , & -(b'-\beta'), & . , & \gamma' \\ -(b'+\beta'), & -c' , & -\gamma' , & . \end{array}\right) \text{ and } \therefore\ (\mathrm{X}')^{-1}=\frac{1}{\mathrm{D}'-\Delta'}\left(\begin{array}{cccc} . , & \gamma' , & -c' , & b'-\beta' \\ -\gamma' , & . , & b'+\beta', & -a' \\ c' , & -(b'+\beta'), & . , & \alpha' \\ -(b'-\beta'), & a' , & -\alpha , & . \end{array}\right)$$

where $\mathrm{D}'=a'c'-b'^2$, $\Delta'=\alpha'\gamma'-\beta'^2$; then

$$(\mathrm{X}\!\between\!\mathrm{X}')+(\mathrm{D}-\Delta)(\mathrm{D}'-\Delta')(\mathrm{X}'^{-1}\!\between\!\mathrm{X}^{-1}),$$

or, what is the same thing,

$$(\mathrm{X}\between\mathrm{X}')+(\mathrm{D}-\Delta)(\mathrm{D}'-\Delta')\big((\mathrm{X}\between\mathrm{X}')\big)^{-1}$$

is to a factor *près* equal to the matrix unity; viz. writing

$$\Lambda=a\alpha+2b\beta+c\gamma+a'\alpha'+2b'\beta'+c'\gamma',$$

the foregoing expression is

$$=\Lambda\left(\begin{array}{cccc} 1 & . & . & . \\ . & 1 & . & . \\ . & . & 1 & . \\ . & . & . & 1 \end{array}\right).$$

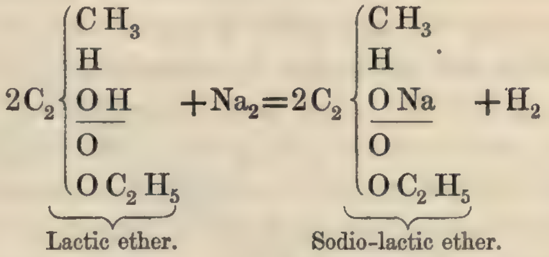
The theorem is verified without difficulty by merely forming the expressions of the compound matrices $(\mathrm{X}\between\mathrm{X}')$ and $(\mathrm{X}'^{-1}\between\mathrm{X}^{-1})$.

III. *Synthetical Researches on Ethers.*—No. 1. *Synthesis of Ethers from Acetic Ether.*

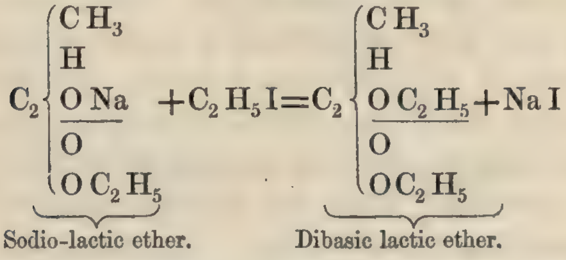
By E. Frankland, *F.R.S., and* B. F. Duppa, *Esq.*

Received July 13,—Read November 16, 1865.

In his researches upon lactic acid Wurtz[*] contends with considerable force for the dibasicity of this acid, supporting his view by the transformation of monobasic into dibasic lactic ether by the consecutive action of sodium and iodide of ethyl, as expressed in the following equations:



$$2C_2\underbrace{\left\{\begin{array}{l}CH_3\\ H\\ \underline{OH}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Lactic ether.}}+Na_2=2C_2\underbrace{\left\{\begin{array}{l}CH_3\\ H\\ \underline{ONa}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Sodio-lactic ether.}}+H_2$$



$$C_2\underbrace{\left\{\begin{array}{l}CH_3\\ H\\ \underline{ONa}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Sodio-lactic ether.}}+C_2H_5I=C_2\underbrace{\left\{\begin{array}{l}CH_3\\ H\\ \underline{OC_2H_5}+NaI\\ O\\ OC_2H_5\end{array}\right.}_{\text{Dibasic lactic ether.}}$$

During the prosecution of our researches upon acids of the lactic series[†], we have obtained several so-called dibasic ethers of this description; but before finally deciding upon the interpretation to be put upon such reactions, it appeared advisable to ascertain the effect of the same reagents upon a well-defined monobasic ether. For this purpose acetic ether was selected, and was treated, first, with sodium, and then with the iodides of ethyl, methyl, and amyl respectively. The results, although not strictly analogous with those obtained under similar circumstances with ethers of the lactic series, are highly remarkable. We have already briefly referred to them in a note presented to the Royal Society in April 1865[‡].

Action of Sodium and Ethyl Iodide upon Acetic Ether.

The acetic ether used for this and the succeeding reactions was made as follows:—6000 grms. of previously dried and fused sodium acetate was broken into small pieces and placed in a copper still immersed in cold water. Over this was gradually poured 12600 grms. of a mixture of 3600 grms. alcohol* of 97 per cent., and 9000 grms. concentrated sulphuric acid, taking care that the temperature did not rise high enough to distil off any of the product. The success of the operation depends greatly upon the mode of mixing the alcohol and sulphuric acid, which ought to be performed as follows. The sulphuric acid being placed in a deep stoneware vessel of sufficient capacity, the alcohol is conducted to the bottom of it by means of a piece of narrow glass tube, connected by a caoutchouc tube with a convenient reservoir standing at a considerable elevation. The glass tube is used as an agitator during the continuance of the flow of the alcohol. In this way there is obtained, without loss of alcohol, a high temperature which greatly favours the formation of sulphovinic acid. This mixture must be allowed to stand, carefully covered up, for twenty-four hours before use.

---

[*] Ann. de Ch. et de Phys. t. lix. p. 161.

[†] Proceedings of the Royal Society, vol. xii. p. 396; vol. xiii. p. 140; vol. xiv. pp. 17, 79, 83, 191, and 197.

[‡] *Ibid.* vol. xiv. p. 198.

It is also advisable to make the admixture of sulphovinic acid and sodium acetate at least twelve hours before the distillation is commenced. The latter operation can then be performed over a naked fire or gas-flame, and continued till water alone passes over. In this way there was obtained 6000 grms. of an acetic ether absolutely free from alcohol, and which, without previous washing, only needs one rectification from fused and powdered chloride of calcium to fit it for the action of sodium. A determination of its vapour-density gave the number 2·9. Pure acetic ether requires 3·04.

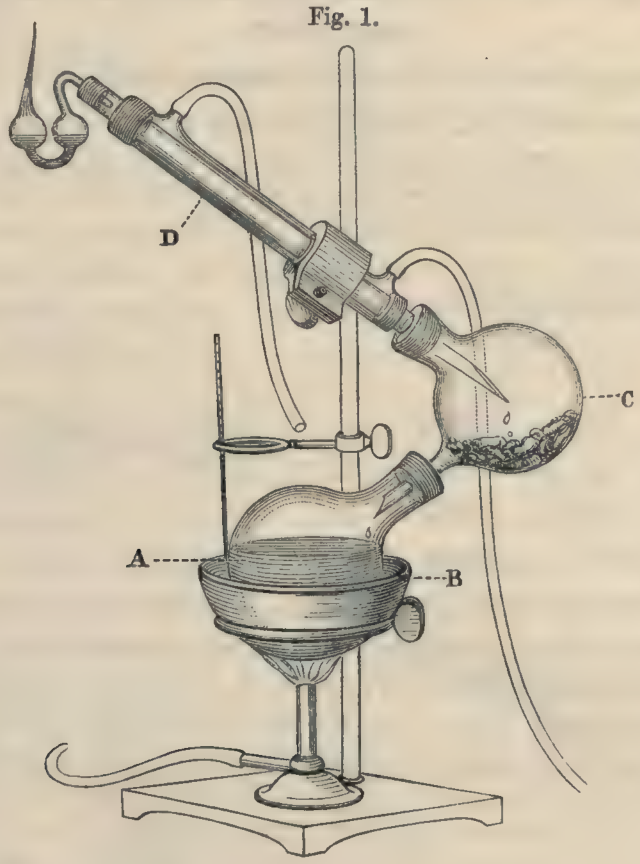
When acetic ether thus prepared is placed in contact with sodium it becomes hot, and a considerable quantity of gas is evolved, which, after being passed first through alcohol and then through water, burns with a non-luminous flame, and the products of combustion do not produce the slightest turbidity on agitation with baryta-water. In fact the gas is pure hydrogen. When the action is complete, the liquid solidifies on cooling to a mass resembling yellow beeswax. By putting the sodium into the acetic ether as just described, it is difficult to conduct the operation to completion, owing to the liquid gradually assuming such a thick and pasty condition as to prevent the further action of the sodium. We therefore adopted the following modification, which enabled us to push the reaction almost to its extreme limit.

A (fig. 1) is a flask containing the acetic ether, and standing in an oil-bath, B. The neck of the flask was closed with a caoutchouc cork, through which passed the beak of the quilled receiver C, containing the sodium cut up into pieces about 1 inch square and $\frac{1}{4}$ inch thick. Into the wide neck of this receiver was inserted an inverted LIEBIG'S condenser, D, which projected sufficiently into the vessel to allow the condensed liquid to drip back upon the sodium. Heat being applied to the oil-bath, the acetic ether soon began to boil, and by its condensation in C and D not only kept the surface of the sodium constantly moist with fresh portions of acetic ether, but also dissolved off the solid sodium-compound as fast as formed. As the operation progressed it was found necessary to raise the temperature of the oil-bath, so as to cause the continuous distillation of the remaining acetic ether, which acquired a higher boiling-point as the proportion of sodium-compound dissolved in it increased; but the temperature ought not to be allowed to rise above 130° C. When the acetic ether ceases to distil at this temperature, the proportion of sodium dissolved is not much below one atom for each atomic proportion of acetic ether employed, and it was not found advantageous to push the reaction further. The contents of the flask were now submitted to the action of ethyl iodide, for which purpose they were transferred whilst still liquid to an iron digester, and mixed with a quantity of ethyl iodide equivalent to the amount of sodium dissolved. The digester was then exposed to a temperature of 100° C. in a steam-bath for several hours, and after being allowed to cool, water in considerable bulk was introduced, and the whole submitted to distillation in an oil-bath. There first came over a large quantity of ethylic ether mixed with some acetic ether that had escaped decomposition. As the temperature in the interior of the digester rose above 100°, the distillate began to separate into an aqueous and an ethereal portion, and further quantities of water were repeatedly added until no more ethereal liquid distilled. The ethereal, separated from the aqueous portion, presented the appearance of a light straw-coloured oil, possessing a pleasant and fragrant odour. It was washed with water, then dried over calcium chloride, and submitted to fractional distillation, by which traces of alcohol, acetic ether, and ethyl iodide were effectually removed from the other products,

---

* Methylated spirit may be used for this purpose.

Fig. 1.



which now boiled between 120° and 265° C. It will be most convenient to describe the constituents of this complex liquid under two distinct heads, viz.—

1st. Products depending upon the duplication of the atom of acetic ether.

2nd. Products derived from the replacement of hydrogen in the methyl of acetic ether by the alcohol-radicals.

In order successfully to separate the two products from each other, and especially to disentangle their constituent compounds, it is absolutely necessary to operate upon large quantities of material. But if this be done, there is obtained a considerable quantity of the products of the first division boiling between 204° and 208° C., whilst the products of the second division boil considerably below these temperatures.

α. Examination of the products depending upon the duplication of the atom of acetic ether.

Submitted to analysis, this liquid gave the following numbers:—

I. ·3920 grm. gave ·9010 grm. carbonic acid and ·3291 grm. water.

II. ·2772 grm. gave ·6347 grm. carbonic acid and ·2338 grm. water.

These numbers agree very closely with the formula

$$C_9 H_{16} O_3,$$

as the following comparison shows;

	Calculated.		Found.		
			I.	II.	Mean.
C_9 . .	108	62·79	62·75	62·45	62·60
H_{16} . .	16	9·22	9·33	9·37	9·35
O_3 . .	48	27·99			
	172	100·00			

In addition to this very close correspondence between the experimental and calculated values, a vapour-density determination gave the number 6·001, the above formula requiring 5·94; nevertheless the body in question is not a single substance, for after being boiled for several hours with aqueous potash, its boiling-point rose to between 210° and 212°, and on being again submitted to analysis it gave results required by the formula

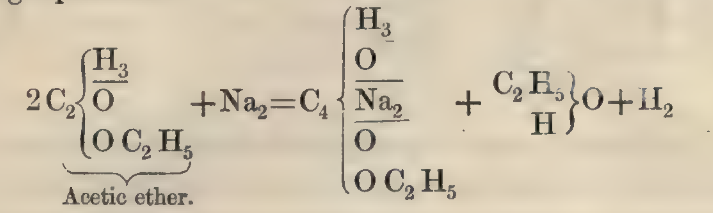
$$C_{10} H_{18} O_3.$$

I. ·2626 grm. gave ·6184 grm. carbonic acid and ·2308 grm. water.

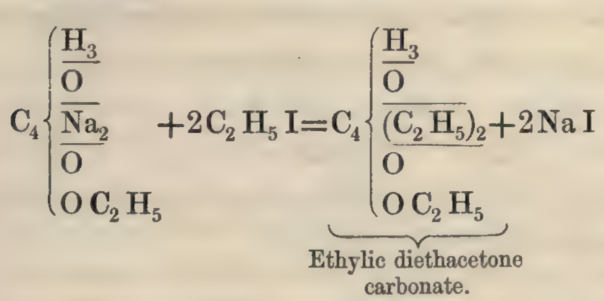
II. ·3339 grm. gave ·7896 grm. carbonic acid and ·2924 grm. water.

	Calculated.		Found.		
			I.	II.	Mean.
C_{10} . .	120	64·52	64·22	64·49	64·36
H_{18} . .	18	9·68	9·77	9·73	9·75
O_3 . .	48	25·80			
	186	100·00			

From considerations which are fully entered into below, we propose for this body the name *ethylic diethacetone carbonate.* The formation of this compound is explained in the following equations:—



$$\underbrace{2\,C_2\left\{\begin{matrix}\underline{H_3}\\ O\\ O\,C_2\,H_5\end{matrix}\right.}_{\text{Acetic ether.}} + Na_2 = C_4\left\{\begin{matrix}H_3\\ \underline{O}\\ \underline{Na_2}\\ O\\ O\,C_2\,H_5\end{matrix}\right. + \left.\begin{matrix}C_2\,H_5\\ H\end{matrix}\right\}O + H_2$$



$$C_4\left\{\begin{matrix}\underline{H_3}\\ \underline{O}\\ \underline{Na_2}\\ O\\ O\,C_2\,H_5\end{matrix}\right. + 2\,C_2\,H_5\,I = \underbrace{C_4\left\{\begin{matrix}\underline{H_3}\\ \underline{O}\\ \underline{(C_2\,H_5)_2}\\ O\\ O\,C_2\,H_5\end{matrix}\right.}_{\text{Ethylic diethacetone carbonate.}} + 2\,Na\,I$$

Ethylic diethacetone carbonate is a colourless and somewhat oily liquid, possessing a fragrant odour and a pungent taste. It is insoluble in water, but miscible in all proportions with alcohol or ether. Its specific gravity is ·9738 at 20° C. It boils between 210° and 212°, and distils unchanged. The density of its vapour was calculated from the following numbers to be 6·59.

Weight of liquid	·1978 grm.
Observed volume of vapour	46·01 cub. centims.
Temperature of bath	232° C.
Height of barometer	767 millims.
Difference of heights of mercury inside and outside tube	76·5 millims.
Height of spermaceti column reduced to millims. of mercury	15·1 millims.

The above formula, corresponding to two volumes, requires the number 6·43.

Boiling aqueous solutions of potash and soda have scarcely any action on ethylic diethacetone carbonate, but baryta-water and lime-water decompose it with great facility, as do also boiling alcoholic solutions of potash and soda. In all these cases a carbonate of the base is precipitated, whilst alcohol and a light ethereal liquid are produced.

This liquid, freed from alcohol by repeated washing with salt and water, boiled, after drying over calcium chloride, between 137°·5 and 139° C. Submitted to analysis, it yielded the following results:

·2075 grm. gave ·5594 grm. carbonic acid and ·2313 grm. water.

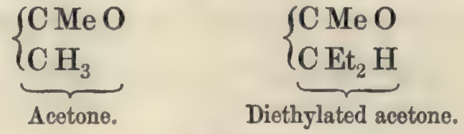
These numbers agree with the formula

$$C_7\,H_{14}\,O,$$

as seen from the following comparison:

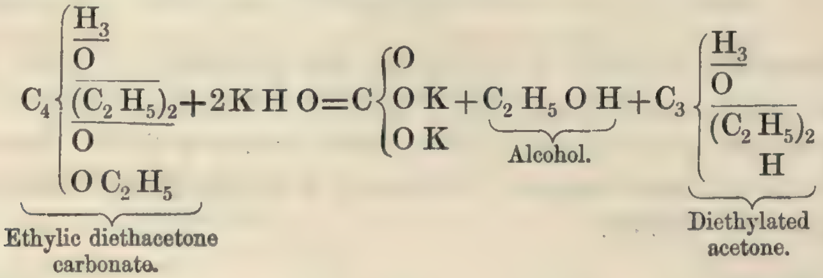
	Calculated.		Found.
C_7 . . .	84	73·68	73·52
H_{14} . . .	14	12·28	12·38
O . . .	16	14·04	
	114	100·00	

From the mode of its formation, and its analogy with other similar bodies described below, this ethereal liquid must be regarded as a ketone, and we propose for it the name *diethylated acetone*. Its rational formula and its relations to acetone may be thus expressed:



$$\underbrace{\left\{\begin{array}{l}C\,Me\,O\\ C\,H_3\end{array}\right.}_{\text{Acetone.}} \qquad \underbrace{\left\{\begin{array}{l}C\,Me\,O\\ C\,Et_2\,H\end{array}\right.}_{\text{Diethylated acetone.}}$$

Diethylated acetone is produced from ethylic diethacetone carbonate by the action of alcoholic potash according to the following equation:



$$\underbrace{C_4\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ (C_2H_5)_2\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Ethylic diethacetone carbonate.}} + 2K\,H\,O = C\left\{\begin{array}{l}O\\ O\,K\\ O\,K\end{array}\right. + \underbrace{C_2\,H_5\,O\,H}_{\text{Alcohol.}} + \underbrace{C_3\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ (C_2H_5)_2\\ \quad H\end{array}\right.}_{\text{Diethylated acetone.}}$$

Diethylated acetone is a colourless, transparent and mobile liquid, possessing a penetrating odour of camphor, and the burning and bitter after-taste of the same substance. It is very slightly soluble in water, but miscible in all proportions with alcohol or ether. Its specific gravity is ·8171 at 22° C. It boils at 137°·5 to 139° C. A determination of its vapour-density by GAY LUSSAC's method gave the following data:—

Weight of diethylated acetone	·1930 grm.
Observed volume of vapour	62·0 cub. centims.
Temperature of bath	161° C.
Height of barometer	773 millims.
Difference of heights of mercury inside and outside tube . .	39·5 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

From these numbers the density was calculated to be 3·86; the formula $C_7\,H_{14}\,O$ requires the number 3·93. Diethylated acetone does not oxidize in the air, neither does it reduce ammoniacal solution of silver nitrate when boiled with it. Mixed with concentrated solution of sodium bisulphite, it forms an oily compound which scarcely exhibits signs of crystallization at 0° C. It suffers no alteration by prolonged boiling with alcoholic potash. It is isomeric with butyrone, with a ketone obtained by FITTIG * in the distillation of a mixture of valeraldehyde and quicklime, and with œnanthol. From the first two it is distinguished by its lower boiling-point (138°), butyrone boiling at 144° C., and FITTIG'S ketone at 161° to 164°, and from the third by its different properties, which are essentially those of a ketone and not of an aldehyde. The difference in structure of three of these bodies may be expressed with considerable certainty by the following formulæ :—

---

* Ann. der Ch. und Pharm. Bd. cxvii. p. 68.

$$\underbrace{\left\{\begin{array}{l} \mathrm{C\,Me\,O} \\ \mathrm{C\,Et_2\,H} \end{array}\right.}_{\text{Diethylated acetone.}} \qquad \underbrace{\left\{\begin{array}{l} \mathrm{C\,(C_3\,H_7)O} \\ \mathrm{C\,Et\,H_2} \end{array}\right.}_{\text{Butyrone.}} \qquad \underbrace{\left\{\begin{array}{l} \mathrm{C\,H\,O} \\ \mathrm{C\,(C_5\,H_{11})H_2} \end{array}\right.}_{\text{Œnanthol.}}$$

We have mentioned above that ethylic diethacetone carbonate is freed from another body with which it is associated, by long ebullition with aqueous potash. A large quantity of potassium carbonate is formed in this reaction, and there is at the same time a volatile body of a ketonic character set free. This led us to suspect the presence in the original mixture of a lower homologue formed by the action of only one atom of sodium upon two atoms of acetic ether—a suspicion supported by the composition of the mixture as shown by the analyses given at page 40, which indicate the formula

$$C_9\,H_{16}\,O_3$$

that would be deduced from the analysis of equal weights of ethylic diethacetone carbonate ($C_{10}\,H_{18}\,O_3$), and its lower homologue, ethylic ethacetone carbonate ($C_8\,H_{14}\,O_3$). Further investigation of the mixture before boiling with aqueous potash completely confirmed this surmise; for by careful fractional distillation we succeeded in separating two liquids of constant boiling-point, one of which was ethylic diethacetone carbonate, and the other *ethylic ethacetone carbonate.* The latter yielded on analysis the following numbers. ·2411 grm. gave ·5387 grm. carbonic acid and ·1944 grm. water.

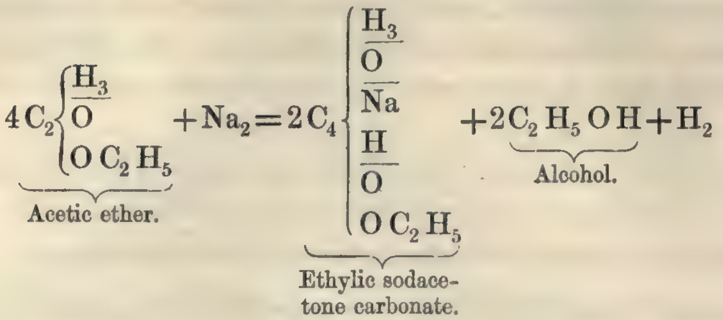
These numbers correspond well with the formula

$$C_4\left\{\begin{array}{l} H_3 \\ \hline O \\ \hline H \\ C_2\,H_5 \\ \hline O \\ O\,C_2\,H_5 \end{array}\right.$$

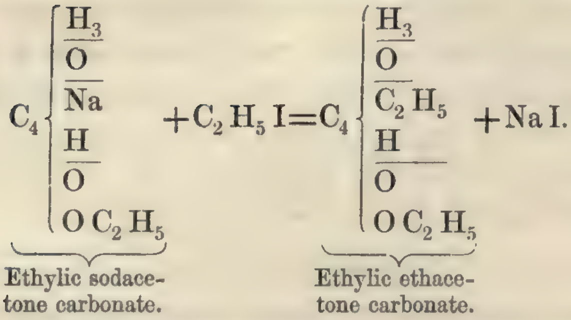
as is seen from the subjoined comparison:

	Calculated.		Found.
C_8 . . .	96	60·76	60·94
H_{14} . .	14	8·86	8·96
O_3 . . .	48	30·38	
	158	100·00	

The production of ethylic ethacetone carbonate by the action of sodium and ethyl iodide upon acetic ether is explained in the two following equations*:



$$\underbrace{4C_2\left\{\begin{array}{l}H_3\\\hline O\\ OC_2H_5\end{array}\right.}_{\text{Acetic ether.}}+Na_2=\underbrace{2C_4\left\{\begin{array}{l}H_3\\\hline O\\\hline Na\\ H\\\hline O\\ OC_2H_5\end{array}\right.}_{\text{Ethylic sodacetone carbonate.}}+\underbrace{2C_2H_5OH}_{\text{Alcohol.}}+H_2$$



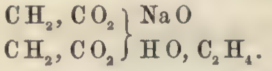
$$\underbrace{C_4\left\{\begin{array}{l}H_3\\\hline O\\\hline Na\\ H\\\hline O\\ OC_2H_5\end{array}\right.}_{\text{Ethylic sodacetone carbonate.}}+C_2H_5I=\underbrace{C_4\left\{\begin{array}{l}H_3\\\hline O\\\hline C_2H_5\\ H\\\hline O\\ OC_2H_5\end{array}\right.}_{\text{Ethylic ethacetone carbonate.}}+NaI.$$

Ethylic ethacetone carbonate is a colourless and transparent liquid, possessing a very fragrant odour and an aromatic taste. It is nearly insoluble in water, but miscible in all proportions with alcohol and ether. Its density in the liquid condition is ·9834 at 16° C. It boils at 195° C., and distils without decomposition. A determination of its vapour-density gave the following data:—

Weight of ethylic-ethacetone carbonate	·1993 grm.
Observed volume of vapour	54·09 cub. centims.
Height of barometer	763·5 millims.
Difference of heights of mercury inside and outside tube .	76·0 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

---

* Whilst engaged in these experiments we became aware, through the 'Jahresbericht der Chemie,' that this compound, and the corresponding one made with iodide of methyl mentioned below, had already been studied by GEUTHER, who also obtained ethylic sodacetone carbonate, which he analyzed and designated by the name *Di-methylene-carbon-ethylene-sodic ether*, assigning to it the formula ($C=12$, $O=8$),



$$\left.\begin{array}{l}CH_2, CO_2\\ CH_2, CO_2\end{array}\right\}\begin{array}{l}NaO\\ HO, C_4H_4.\end{array}$$

From this body he produced ethylic ethacetone carbonate (*Di-methylene-carbon-ethylene ether*) by the action of ethyl iodide, and also *ethylic methacetone carbonate* (*Di-methylene-carbon-methylene ether*) by the action of methyl iodide. Our analytical results and observations of the physical properties of these two bodies agree completely with those assigned to them by GEUTHER, whose isolation of the sodium-compound, attended as it is with great difficulties, serves to impart a completeness to the reaction which it would otherwise have lacked.

From these numbers the specific gravity was calculated to be 5·36; theory requires 5·45. Ethylic ethacetone carbonate, unlike ethylic-diethacetone carbonate, and in opposition to GEUTHER'S statement, is readily attacked by boiling aqueous solutions of potash and soda, yielding carbonates of these bases, alcohol, and *ethylated acetone* according to the following equation:—

$$\underbrace{C_4\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_2\,H_5\\ \underline{H}\\ O\\ O\,C_2\,H_5\end{array}\right.}_{\text{Ethylic ethacetone carbonate.}} + 2KHO = C\left\{\begin{array}{l}O\\ OK\\ O\,K\end{array}\right. + \underbrace{C_2H_5O\,H}_{\text{Alcohol.}} + \underbrace{C_3\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_2\,H_5\\ H_2\end{array}\right.}_{\text{Ethylated acetone.}}$$

Ethylic ethacetone carbonate is still more readily decomposed by aqueous solution of baryta or by alcoholic potash; in both cases ethylated acetone and a carbonate of the base are produced.

Ethylated acetone may be freed from alcohol by repeated washing with salt and water, but it is best obtained in a state of absolute purity by combination with, and subsequent separation from sodium bisulphite. Ethylated acetone thus purified and rectified from quicklime, gave on analysis the following numbers:—

·1483 grm. gave ·3799 grm. carbonic acid and ·1575 grm. water.

This result agrees well with the formula

$$C_5\,H_{10}\,O,$$

as seen from the following comparison of experimental with theoretical percentage numbers:—

Calculated.			Found.
C_5 . .	60	69·77	69·86
H_{10} . .	10	11·63	11·80
O . .	16	18·60	
	86	100·00	

The formula of ethylated acetone given above may be reduced to the radical type as follows:—

$$C_3\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_2\,H_5\\ H_2\end{array}\right. = C_2\left\{\begin{array}{l}C\,H_3\\ \underline{O}\\ C_2\,H_5\\ H_2\end{array}\right. = \left\{\begin{array}{l}C\,Me\,O\\ C\,Et\,H_2\end{array}\right.$$

Its relations to acetone and diethylated acetone are then clearly seen in the following formulæ:—

$$\underbrace{\left\{\begin{matrix}\text{C Me O}\\ \text{C H}_3\end{matrix}\right.}_{\text{Acetone.}} \qquad \underbrace{\left\{\begin{matrix}\text{C Me O}\\ \text{C Et H}_2\end{matrix}\right.}_{\text{Ethylated acetone.}} \qquad \underbrace{\left\{\begin{matrix}\text{C Me O}\\ \text{C Et}_2\text{ H}\end{matrix}\right.}_{\text{Diethylated acetone.}}$$

Ethylated acetone is a colourless, transparent and very mobile liquid, possessing a powerful and pleasant odour, in which that of camphor is slightly perceptible. Its specific gravity is ·8132 at 13° C., and ·8046 at 22° C. It boils steadily at 101° (barom. 760 millims.), and its vapour has the density 2·951, as calculated from the following data, theory requiring 2·971.

Weight of ethylated acetone	·1368 grm.
Observed volume of vapour	55·64 cub. centims.
Temperature of bath	124° C.
Height of barometer	773 millims.
Difference of heights of mercury inside and outside tube . .	80 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

Ethylated acetone neither absorbs oxygen from the air, nor reduces ammoniacal solutions of silver. It yields with concentrated solution of sodium bisulphite a compound in large and brilliant crystals, which are quite permanent in the air, and which at once distinguish it from diethylated acetone, the latter producing under the same circumstances an oily compound. Ethylated acetone is not altered by prolonged ebullition with alcoholic potash. Its relations to numerous isomers are described below.

β. *Examination of the products derived from the replacement of hydrogen by ethyl in the methyl of acetic ether.*

This portion of the original product derived from the action of sodium and ethylic iodide upon acetic ether, and which boiled considerably below the portion α, was sub mitted to repeated rectifications, and was thus resolved to a great extent into two ethereal liquids, one of them boiling between 118° and 122°, and the other between 150° and 157° C. On treating these liquids with boiling baryta-water for several hours in order to remove traces of ethylic diethacetone carbonate and ethylic ethacetone carbonate, the point of ebullition of the first was rendered quite constant at 119° C., and that of the second at 151° C.

Submitted to analysis, the first of these liquids yielded the following results:—

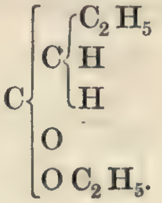
I. ·1716 grm. gave ·3922 grm. carbonic acid and ·1626 grm. water.
II. ·2190 grm. gave ·5007 grm. carbonic acid and ·2063 grm. water.

These numbers coincide closely with those calculated from the formula

$$C_6\,H_{12}\,O_2.$$

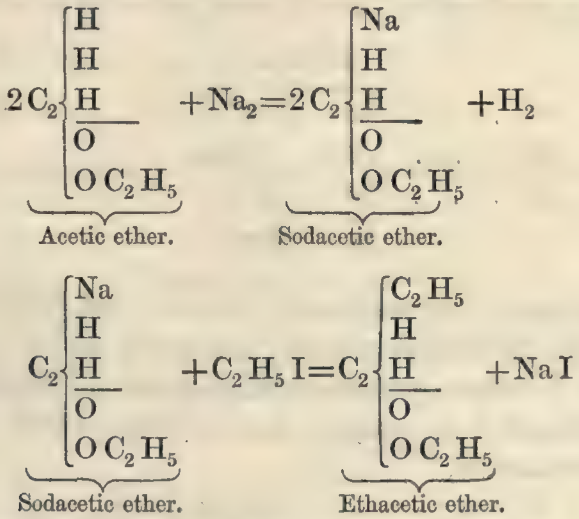
	Calculated.		Found. I.	Found. II.	Mean.
C_6	72	62·07	62·33	62·35	62·34
H_{12}	12	10·35	10·53	10·47	10·50
O_2	32	27·58			
	116	100·00			

The formula and habits of this compound show it to be *ethacetic ether*:



$$C\begin{cases}C\begin{cases}C_2H_5\\H\\H\end{cases}\\O\\O\,C_2H_5.\end{cases}$$

Ethacetic ether is produced from acetic ether by the following reactions:—



$$\underbrace{2C_2\begin{cases}H\\H\\H\\O\\O\,C_2H_5\end{cases}}_{\text{Acetic ether.}}+Na_2=\underbrace{2C_2\begin{cases}Na\\H\\H\\O\\O\,C_2H_5\end{cases}}_{\text{Sodacetic ether.}}+H_2$$

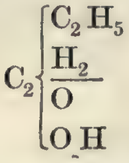
$$\underbrace{C_2\begin{cases}Na\\H\\H\\O\\O\,C_2H_5\end{cases}}_{\text{Sodacetic ether.}}+C_2H_5I=\underbrace{C_2\begin{cases}C_2H_5\\H\\H\\O\\O\,C_2H_5\end{cases}}_{\text{Ethacetic ether.}}+NaI$$

Ethacetic ether possesses all the properties of butyric ether. It is colourless and transparent, and when largely diluted with alcohol possesses the characteristic odour of pineapples, which is undistinguishable from that of butyric ether under the same circumstances. Its density is ·8942 at 0° C., that of butyric ether being, according to PIERRE, ·9019 at 0° C., numbers which coincide with each other as closely as could be expected. The boiling-point (119° C.) of ethacetic ether also agrees exactly with that of butyric ether given by the same authority, as does the vapour-density, which was ascertained to be 3·96 from the following data, the theoretical number being 4·04.

Weight of ethacetic ether	·1769 grm.
Observed volume of vapour	57·24 cub. centims.
Temperature of bath	148° C.
Height of barometer	763·5 millims.
Difference of height of mercury inside and outside tube	75·7 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

Ethacetic ether is readily decomposed by boiling alcoholic potash, yielding alcohol and a salt which, when distilled with slight excess of dilute sulphuric acid, gives a powerfully acid oily liquid, tolerably soluble in water, possessing in a high degree the characteristic odour of butyric acid, and boiling fixedly at 161° C. The boiling-point of butyric acid has been variously stated by different observers: PELOUZE and GELIS state it to be 164°, whilst KOPP gives it as 157° at 760 millims. pressure.

Submitted to analysis, ·2439 grm. *ethacetic acid* gave ·4862 grm. carbonic acid and ·2030 grm. water, numbers which correspond with the formula

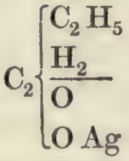


$$C_2\left\{\begin{array}{l} C_2H_5 \\ \underline{H_2} \\ O \\ OH \end{array}\right.$$

The following is a comparison of the analytical with the calculated numbers:—

	Calculated.		Found.
C_4 . . .	48	54·54	54·37
H_8 . . .	8	9·09	9·25
O_2 . . .	32	36·37	
	88	100·00	

Boiled with water and silver carbonate, ethacetic acid yields, after some hours, a crop of beautiful ramiform needle-like crystals, aggregated into large globular masses, which become anhydrous *in vacuo*; both the mother-liquor and crystals have a faint smell of rancid butter. Submitted to analysis, these crystals yielded results agreeing with the formula for silver ethacetate,



$$C_2\left\{\begin{array}{l} C_2H_5 \\ \underline{H_2} \\ O \\ O\,Ag \end{array}\right.$$

·2738 grm. gave ·2463 grm. carbonic acid, ·0889 grm. water, and ·1518 grm. silver.

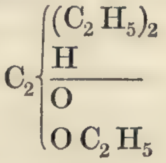
	Calculated.		Found.
C_4 . . .	48	24·61	24·53
H_7 . . .	7	3·59	3·61
Ag . . .	108	55·38	55·44
O_2 . . .	32	16·42	
	195	100·00	

We have been unable to detect any difference between ethacetic acid and butyric acid, and we have stated below our reasons for believing them to be identical.

The second portion of the product β, mentioned above as a liquid boiling at 151° C., was next submitted to analysis.

I. ·2276 grm. gave ·5523 grm. carbonic acid and ·2279 grm. water.
II. ·1839 grm. gave ·4461 grm. carbonic acid and ·1847 grm. water.

These results correspond with the formula of *diethacetic ether*,

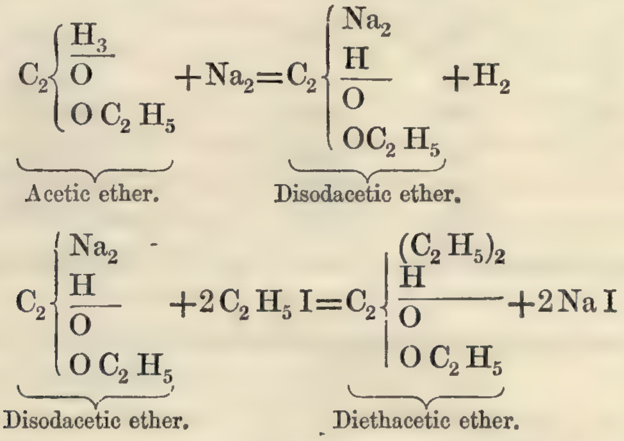


$$C_2\left\{\begin{array}{l}(C_2H_5)_2\\ \underline{H\qquad}\\ O\\ O\,C_2H_5\end{array}\right.$$

as is seen from the following comparison:—

	Calculated.		Found.	
			I.	II.
C_8 . . .	96	66·66	66·18	66·16
H_{16} . . .	16	11·11	11·13	11·16
O_2 . . .	32	22·23		
	144	100·00		

Diethacetic ether is derived from acetic ether by the following reactions:—



$$\underbrace{C_2\left\{\begin{array}{l}\underline{H_3}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Acetic ether.}} + Na_2 = \underbrace{C_2\left\{\begin{array}{l}Na_2\\ \underline{H\quad}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Disodacetic ether.}} + H_2$$

$$\underbrace{C_2\left\{\begin{array}{l}Na_2\\ \underline{H\quad}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Disodacetic ether.}} + 2\,C_2H_5I = \underbrace{C_2\left\{\begin{array}{l}(C_2H_5)_2\\ \underline{H\qquad}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Diethacetic ether.}} + 2\,NaI$$

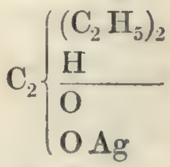
Diethacetic ether is a colourless and transparent liquid of a peculiar and fragrant odour, and a taste somewhat like peppermint. Its specific gravity is ·8822 at 0° C. It is insoluble in water, but miscible in all proportions with alcohol and ether. It boils constantly at 151° C., and its vapour has, theoretically, the density 4·98. Experimentally the number 5·00 was obtained from the following data:—

Weight of diethacetic ether	·1697 grm.
Observed volume of vapour	48·23 cub. centims.
Temperature of bath	168° C.
Height of barometer	758 millims.
Difference of heights of mercury inside and outside tube . .	109 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

Treated with alcoholic potash, diethacetic ether is readily decomposed, yielding alcohol and potassium diethacetate. By distilling the latter with dilute sulphuric acid, diethacetic acid passes over and floats on the surface of the water which accompanies it. This acid reddens litmus-paper powerfully, is but sparingly soluble in water, and emits a peculiar odour quite different from that of caproic acid, with which diethacetic acid is isomeric. Boiled with water and silver carbonate, it yields, on filtration and evaporation *in vacuo*, splendid fern-like crystals, which, after pressing between folds of blotting-paper and drying *in vacuo*, with the exclusion of light, are perfectly white, with a satiny lustre; they possess great elasticity, and are remarkably like asbestos. In a strong light they rapidly become brown. Submitted to analysis,

·1990 grm. gave ·2325 grm. carbonic acid, ·0902 grm. water, and ·0980 grm. metallic silver.

These numbers agree with the formula

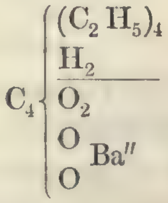


$$C_2\left\{\begin{array}{l}(C_2H_5)_2\\ H\\ \hline O\\ O\,Ag\end{array}\right.$$

	Calculated.		Found.
C_6 . .	72	32·28	31·86
H_{11} . .	11	4·93	5·04
Ag . .	108	48·43	49·25
O_2 . .	32	14·36	13·85
	223	100·00	100·00

Barium diethacetate is very soluble in water, and on evaporation forms a beautifully crystalline mass.

A determination of barium in this salt yielded 38·05 per cent.; the formula



$$C_4\left\{\begin{array}{l}(C_2H_5)_4\\ H_2\\ \hline O_2\\ \begin{array}{l}O\\ O\end{array}Ba''\end{array}\right.$$

requires 37·33 per cent. of barium.

Diethacetic acid differs markedly from caproic acid in its odour, as above mentioned, whilst the compounds of the two acids scarcely permit of their being confounded with each other. Thus diethacetic ether differs from caproic ether by 11° in its boiling-point, which is 151° C., the boiling-point of caproic ether being, according to FEHLING, 162°. In their specific gravities also the two ethers appreciably differ, caproic ether having a density of ·882 at 18° C., whilst the specific gravity of diethacetic ether is ·8822 at 0° C. The silver salts differ widely in their crystalline form, solubility in water, and sensitiveness to the influence of light. Silver caproate crystallizes in large and very thin plates, which are nearly insoluble in water and but very slightly sensitive to light, whilst silver dieth-acetate is deposited in frond-like crystals, which are quite as soluble as silver acetate, and become rapidly brown when exposed to light. We therefore conclude that these acids are isomeric and not identical. Theoretical considerations leading to the same conclusion are given below.

Action of Sodium and Methyl Iodide upon Acetic Ether.

Acetic ether was treated with sodium, as in the corresponding reaction described above; but in the subsequent treatment of the sodium-compound it was not found necessary to expose the mixture of the latter with methyl iodide to heat in a digester. These materials act upon each other with great energy and completeness at a temperature below the boiling-point of methyl iodide. At the conclusion of the sodium-reaction, therefore, the temperature was allowed to fall until the liquid in the flask began to solidify, and the receiver, C (see figure, p. 39), with the residue of sodium being removed, the extremity of the condenser was inserted into the neck of the flask. Methyl iodide in excess was then slowly added by pouring it down the condenser. An energetic action immediately took place, a large quantity of sodium iodide being formed. To complete this reaction, one atom of methyl iodide for each atom of sodium employed was found to be sufficient. The ethereal part of the product in the flask now remained liquid, even after cooling, the sodium iodide subsiding as a dense precipitate. Water was then added, and the contents of the flask submitted to distillation. Water, alcohol, and an oily liquid which floated on the aqueous portion of the distillate, condensed in the receiver. When the oily liquid ceased to come over, the contents of the retort were slightly acidified with dilute sulphuric acid, more water added, and the distillation continued into a fresh receiver. The acid distillate thus obtained did not contain any formic acid, and consisted chiefly of acetic acid, with traces of other higher acids belonging to the same series.

The aqueous portion of the distillate was separated from the oily, and submitted to distillation in an oil-bath. A considerable quantity of a spirituous liquid passed over, which, after rectification from quicklime, boiled at 78°·5, and consisted of pure alcohol. It yielded on combustion 52·29 per cent. of carbon and 12·98 per cent. of hydrogen. Alcohol requires 52·17 per cent. of carbon and 13·04 per cent. of hydrogen.

The oily portion of the distillate was repeatedly washed with water, dried over calcium chloride, and rectified. It began to boil at 75°, but the thermometer rapidly rose to 183°, between which temperature and 184° nearly the whole of the remaining large portion of liquid came over.

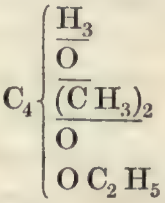
Notwithstanding the constancy of boiling-point of this liquid, numerous analyses showed it to be a mixture, and the numbers obtained were consistent with the assumption that it was composed of two bodies having respectively the formulæ

$$C_7 H_{12} O_3 \text{ and } C_8 H_{14} O_3.$$

In fact it was evident that the liquid with which we had now to do was the exact counterpart of the one obtained in the corresponding reaction with ethyl iodide described above, and that it consisted of the homologues produced in the ethylic reaction, viz. *ethylic methacetone carbonate* and *ethylic dimethacetone carbonate.* To separate these compounds, whose boiling-points were evidently nearly if not absolutely identical, we availed ourselves of their different behaviour with boiling aqueous potash; ethylic dimethacetone carbonate, like ethylic diethacetone carbonate, being scarcely affected by this treatment, whilst ethylic methacetone carbonate, like its ethylic homologue, is rapidly decomposed. By thus boiling several ounces of the mixed ethers with aqueous potash, a liquid was obtained which, by repeated rectification, was separated into two products, the one boiling at about 80° C., and the other constantly at 184° C. The latter was submitted to analysis, and yielded the following results:—

I. ·2001 grm. gave ·4435 grm. carbonic acid and ·1598 grm. water.
II. ·1647 grm. gave ·3652 grm. carbonic acid and ·1317 grm. water.
III. ·3040 grm. gave ·6728 grm. carbonic acid and ·2399 grm. water.
IV. ·2739 grm. gave ·6052 grm. carbonic acid and ·2218 grm. water.
V. ·3319 grm. gave ·7388 grm. carbonic acid and ·2721 grm. water.
VI. ·2548 grm. gave ·5686 grm. carbonic acid and ·2075 grm. water.

These numbers approximate closely to those required by the formula of ethylic dimethacetone carbonate,

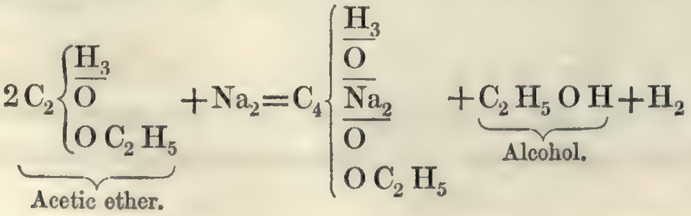


$$C_4\left\{\begin{array}{l}\underline{H_3}\\ O\\ \overline{\underline{(CH_3)_2}}\\ O\\ OC_2H_5\end{array}\right.$$

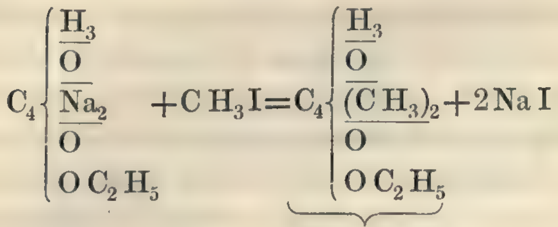
as shown by the following comparison:—

	Calculated.		Found.						
			I.	II.	III.	IV.	V.	VI.	Mean.
C_8 .	96	60·76	60·45	60·47	60·36	60·26	60·71	60·86	60·52
H_{14} .	14	8·86	8·87	8·88	8·77	9·00	9·11	9·05	8·95
O_3 .	48	30·38							
	158	100·00							

The production of ethylic dimethacetone carbonate from acetic ether is explained by the following equations:—



$$\underbrace{2C_2\left\{\begin{array}{l}\underline{H_3}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Acetic ether.}}+Na_2=C_4\left\{\begin{array}{l}\underline{H_3}\\ O\\ \overline{\underline{Na_2}}\\ O\\ OC_2H_5\end{array}\right.+\underbrace{C_2H_5OH}_{\text{Alcohol.}}+H_2$$



$$C_4\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ \underline{Na_2}\\ O\\ O\,C_2H_5\end{array}\right. + C\,H_3I = \underbrace{C_4\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ \underline{(C\,H_3)_2}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Ethylic dimeth-acetone carbonate.}} + 2\,Na\,I$$

Ethylic dimethacetone carbonate is a colourless, slightly oleaginous liquid, possessing a peculiar penetrating pleasant and aromatic odour, and a sharp burning taste. It is scarcely at all soluble in water, but readily so in alcohol or ether. Its specific gravity is ·9913 at 16° C. It boils constantly at 184°, and distils unchanged. A determination of its vapour-density gave the following numbers:—

Weight of ethylic dimethacetone carbonate	·1993 grm.
Observed volume of vapour	54·09 cub. centims.
Temperature of bath	194° C.
Height of barometer	763·5 millims.
Height of internal column of mercury	76·0 millims.
Height of column of spermaceti 253 millims. reduced to millims. of mercury	15·7 millims.

From these data the specific gravity of the vapour was calculated to be 5·36. The above formula, corresponding to two volumes, requires 5·45.

Ethylic dimethacetone carbonate is very slowly acted upon by aqueous solution of potash or soda. A quantity of it was boiled, without any perceptible diminution of its volume, with two separate portions of strong solution of potash for eight or ten hours, an inverted condenser being attached to the flask.

Alcoholic potash in the cold decomposes it very slowly, but when heated to boiling complete decomposition is effected in a very short time. The action is the same as that of baryta-water.

Baryta-water instantly attacks ethylic dimethacetone carbonate in the cold, barium carbonate being immediately precipitated. At 100° C. the decomposition is complete in a few minutes; and on submitting the mixture to distillation, alcohol and a light ethereal liquid pass over. The latter, repeatedly washed with a saturated solution of common salt to remove alcohol, and dried over quicklime, gave on analysis the following numbers:—

I. ·2083 grm. gave ·5301 grm. carbonic acid and ·2220 grm. water.
II. ·2594 grm. gave ·6572 grm. carbonic acid and ·2728 grm. water.

When the mode of its formation is considered, these results show that the body analyzed is *dimethylated acetone*, the true homologue of diethylated acetone, and the isomer of ethylated acetone.

The percentage numbers calculated from its formula,

$$\left\{\begin{array}{l}\mathrm{C\,Me\,O}\\ \mathrm{C\,Me_2\,H},\end{array}\right.$$

agree with those obtained in the above analyses.

	Calculated.		Found.		
			I.	II.	Mean.
C_5 . .	60	69·77	69·41	69·10	69·26
H_{10} . .	10	11·63	11·84	11·68	11·76
O . . .	16	18·60			
	86	100·00			

The production of dimethylated acetone from ethylic dimethacetone carbonate by the action of alcoholic potash is explained in the following equation:—

$$\underbrace{\mathrm{C_4}\left\{\begin{array}{l}\underline{\mathrm{H_3}}\\ \mathrm{O}\\ \overline{\mathrm{(C\,H_3)_2}}\\ \mathrm{O}\\ \mathrm{O\,C_2\,H_5}\end{array}\right.}_{\text{Ethylic dimethacetone carbonate.}} + 2\,\mathrm{K\,H\,O} = \underbrace{\mathrm{C}\left\{\begin{array}{l}\mathrm{O}\\ \mathrm{O\,K}\\ \mathrm{O\,K}\end{array}\right.}_{\text{Potassium carbonate.}} + \underbrace{\mathrm{C_2\,H_5\,O\,H}}_{\text{Alcohol.}} + \underbrace{\mathrm{C_3}\left\{\begin{array}{l}\underline{\mathrm{H_3}}\\ \mathrm{O}\\ \overline{\mathrm{(C\,H_3)_2}}\\ \mathrm{H}\end{array}\right.}_{\text{Dimethylated acetone.}}$$

The above formula for dimethylated acetone is condensed to the radical type as follows:—

$$\mathrm{C_3}\left\{\begin{array}{l}\underline{\mathrm{H_3}}\\ \mathrm{O}\\ \overline{\mathrm{(C\,H_3)_2}}\\ \mathrm{H}\end{array}\right. = \mathrm{C_2}\left\{\begin{array}{l}\mathrm{C\,H_3}\\ \mathrm{O}\\ \overline{\mathrm{Me_2}}\\ \mathrm{H}\end{array}\right. = \left\{\begin{array}{l}\mathrm{C\,Me\,O}\\ \mathrm{C\,Me_2\,H}\end{array}\right.$$

Dimethylated acetone is a colourless, transparent and very mobile liquid, possessing a pleasant odour, reminding at the same time of parsley and acetone. Its specific gravity is ·8099 at 13° C., and it boils at 93°·5 C. A determination of its vapour-density gave the following numbers:—

Weight of dimethylated acetone	·1378 grm.
Observed volume of vapour	58·00 cub. centims.
Temperature of bath	120° C.
Height of barometer	744 millims.
Difference of heights of mercury inside and outside tube . .	75 millims.
Height of spermaceti column reduced to millimetres of mercury	15·3 millims.
Specific gravity of vapour	2·92
Theoretical density calculated from $C_5H_{10}O=2$ vols. . . .	2·97

Dimethylated acetone closely resembles its ethylic homologue in all its chemical properties; like diethylated acetone, it is oxidized with difficulty, and does not very readily form a crystalline compound with sodium bisulphite—differing in the latter respect markedly from its isomer, ethylated acetone, and also from methylated acetone described below.

We have mentioned above that the ethereal liquid from which ethylic dimethacetone carbonate was obtained by ebullition with aqueous potash, contained another body probably homologous with ethylic ethacetone carbonate. The following analyses of the ethereal liquid before ebullition with aqueous potash indicate the presence of this body, which may be appropriately named *ethylic methacetone carbonate.* These analyses were made with the products of several distinct operations.

I. ·4248 grm. gave ·9289 grm. carbonic acid and ·3316 grm. water.
II. ·3008 grm. gave ·6580 grm. carbonic acid and ·2364 grm. water.
III. ·2644 grm. gave ·5774 grm. carbonic acid and ·2104 grm. water.

The following are the percentage results of these analyses:—

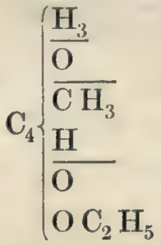
	I.	II.	III.	Mean.
C . .	59·64	59·66	59·56	59·62
H . .	8·67	8·73	8·84	8·75

These numbers coincide very closely with those that would be obtained by the analysis of a mixture of equal weights of ethylic dimethacetone carbonate ($C_8 H_{14} O_3$) and ethylic methacetone carbonate ($C_7 H_{12} O_3$), viz.,

C . . .	59·54
H . . .	8·60

All attempts to separate these two liquids by fractional distillation failed, owing to the close approximation, if not absolute identity, of their boiling-points. In one operation, however, where the action of sodium upon the acetic ether had not been pushed so far, we obtained a product which consisted almost entirely of ethylic methacetone carbonate, as is seen from the following analysis:—

·2624 grm. gave ·5637 grm. carbonic acid and ·2017 grm. water, numbers which approach closely to the formula of ethylic methacetone carbonate.



$$C_4\left\{\begin{array}{l} \underline{H_3} \\ \underline{O} \\ \overline{C\,H_3} \\ \underline{H} \\ O \\ O\,C_2\,H_5 \end{array}\right.$$

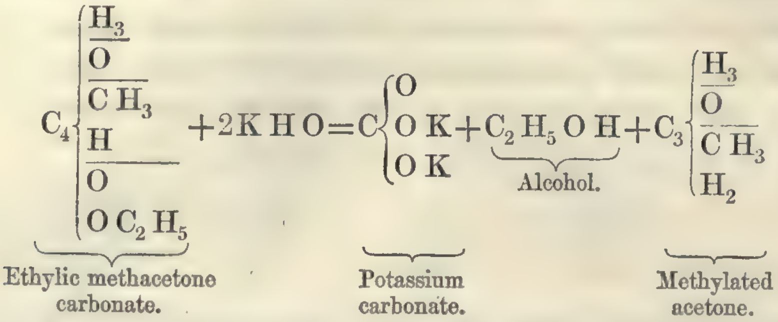
	Calculated.		Found.
C_7 . .	84	58·33	58·59
H_{12} . .	12	8·33	8·54
O_3 . .	48	33·34	
	144	100·00	

Finding that this body had been already obtained in a state of perfect purity by GEUTHER*, we did not make any further attempts to separate it more completely from ethylic dimethacetone carbonate, especially as its presence in the mixtures above analyzed is proved by the isolation of methylated acetone—its derivative ketone, as described below.

---

* Götting. Anzeigen, 1863, p. 281; and Jahresbericht der Chemie, 1863, p. 323.

To the properties of ethylic methacetone carbonate described by GEUTHER, we have only to add that, in opposition to this chemist's statement, it is very readily decomposed by aqueous potash, with the formation of *methylated acetone* according to the following equation:—



$$\underbrace{C_4\left\{\begin{array}{l} \underline{H_3} \\ \underline{O} \\ C\,H_3 \\ \underline{H} \\ O \\ O\,C_2\,H_5 \end{array}\right.}_{\text{Ethylic methacetone carbonate.}} + 2\,K\,H\,O = \underbrace{C\left\{\begin{array}{l} O \\ O\,K \\ O\,K \end{array}\right.}_{\text{Potassium carbonate.}} + \underbrace{C_2\,H_5\,O\,H}_{\text{Alcohol.}} + \underbrace{C_3\left\{\begin{array}{l} \underline{H_3} \\ \underline{O} \\ C\,H_3 \\ H_2 \end{array}\right.}_{\text{Methylated acetone.}}$$

Condensed to the radical type, the formula of methylated acetone becomes

$$\left\{\begin{array}{l} C\,Me\,O \\ C\,Me\,H_2. \end{array}\right.$$

Methylated acetone is best obtained in a state of purity by combining it with sodium bisulphite, pressing the beautiful crystalline compound so formed between folds of blotting-paper to remove traces of dimethylated acetone, exposing it over sulphuric acid *in vacuo*, and then regenerating the methylated acetone by distillation with aqueous potash. The liquid so obtained, after drying over quicklime and rectification, gave the following analytical results:—

I. ·1946 grm. gave ·4759 grm. carbonic acid and ·1981 grm. water.

II. ·1461 grm. gave ·3557 grm. carbonic acid and ·1504 grm. water.

These numbers agree well with the above formula.

	Calculated.		Found.		
			I.	II.	Mean.
C_4 . . .	48	66·66	66·69	66·40	66·55
H_8 . . .	8	11·11	11·31	11·44	11·37
O . . .	16	22·23			
	72	100·00			

Methylated acetone is a colourless, transparent, and very mobile liquid, possessing an odour like chloroform, but more pungent. It is tolerably soluble in water, and more than slightly so in a saturated solution of common salt. Its specific gravity is ·8125 at 13° C. It boils at 81° C., and its vapour-density is 2·52, as given by the following data, the theoretical number being 2·49.

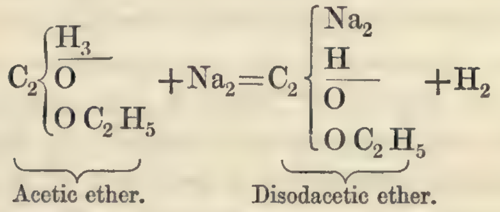
Weight of methylated acetone	·1166 grm.
Observed volume of vapour	55·39 cub. centims.
Temperature of bath	112° C.
Height of barometer	757 millims.

Difference of heights of mercury inside and outside of tube	83·5 millims.
Height of spermaceti column reduced to millims. of mercury	15·7 millims.

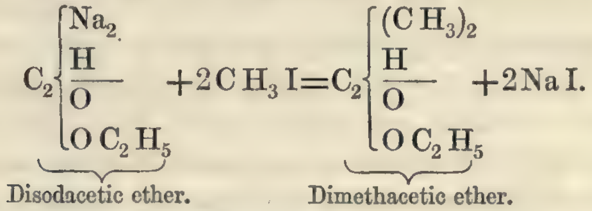
We give below our reasons for concluding that methylated acetone is identical with the ethyl-acetyl described by Freund*, and obtained by acting upon acetyl chloride with zinc ethide.

Methylated acetone forms a splendidly crystalline compound with sodium bisulphite, and in its other chemical properties so closely resembles ethylated acetone as to require no further description. It retains alcohol with such tenacity as to render its separation from that liquid, by washing and treatment with calcium chloride, almost impossible. This separation, however, is readily effected by the action of sodium bisulphite.

We reserve for a future communication the description of the products derived from the replacement of hydrogen, in the methyl of acetic ether, by methyl; but we may mention before leaving the reaction now under consideration, that we have obtained an ether isomeric with butyric ether, the formation of which is explained in the following equations:—



$$\underbrace{C_2\begin{cases}\underline{H_3}\\ O\\ O\,C_2\,H_5\end{cases}}_{\text{Acetic ether.}} + Na_2 = \underbrace{C_2\begin{cases}Na_2\\ \underline{H}\\ O\\ O\,C_2\,H_5\end{cases}}_{\text{Disodacetic ether.}} + H_2$$



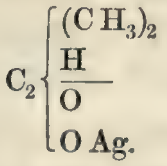
$$\underbrace{C_2\begin{cases}Na_2\\ \underline{H}\\ O\\ O\,C_2\,H_5\end{cases}}_{\text{Disodacetic ether.}} + 2\,C\,H_3\,I = \underbrace{C_2\begin{cases}(C\,H_3)_2\\ \underline{H}\\ O\\ O\,C_2\,H_5\end{cases}}_{\text{Dimethacetic ether.}} + 2\,Na\,I.$$

By acting upon this ether with alcoholic potash it is decomposed, yielding alcohol and potassium dimethacetate. On distilling the latter with dilute sulphuric acid, dimethacetic acid, isomeric with butyric acid, is obtained as an oily liquid tolerably soluble in water. Treated with silver carbonate, it readily gave a crystalline silver-salt, which after being well-washed with water and then dried *in vacuo*, yielded the following results on analysis:—

I. ·3920 grm. gave ·3505 grm. carbonic acid, ·1287 grm. water, and ·2172 grm. metallic silver.

II. ·3837 grm. gave ·3399 grm. carbonic acid, ·1246 grm. water, and ·2135 grm. metallic silver.

These numbers agree well with the formula of silver dimethacetate.



$$C_2\begin{cases}(C\,H_3)_2\\ \underline{H}\\ O\\ O\,Ag.\end{cases}$$

* Ann. der Ch. und Pharm. Bd. cxviii. s. 1.

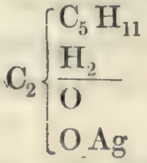
	Calculated.		Found.		Mean.
			I.	II.	
C_4 . . .	48	24·61	24·38	24·16	24·27
H_7 . . .	7	3·59	3·65	3·61	3·63
Ag . . .	108	55·38	55·41	55·64	55·52
O_2 . . .	32	16·42			16·58
	195	100·00			100·00

Action of Sodium and Amylic Iodide upon Acetic Ether.

For this reaction the compounds of sodium derived from acetic ether were prepared as before, and were then submitted to the action of amylic iodide for several hours at the boiling-point of the mixture. When the sodium had all become converted into iodide, water was added and the supernatant liquid decanted. We reserve a complete description of this liquid for our next communication, and will here confine ourselves to the separation from it of œnanthylic acid, which was obtained as follows:—The crude product, after drying over calcium chloride, was submitted to rectification, and the portion boiling between 170° and 190° C. collected apart and decomposed by ebullition with alcoholic potash. By this treatment we destroyed any ethylic amylacetone carbonate and ethylic diamylacetone carbonate that were present, and obtained a potash-salt of an acid derived from acetic acid by the substitution of one atom of amyl for one of hydrogen. The potash-salt thus formed was distilled with excess of sulphuric acid diluted with a large quantity of water. Upon the distillate there floated an oily acid, possessing an odour resembling œnanthylic acid. This acid was converted into an ammonia-salt, from which a silver-salt was prepared by precipitation. After being well washed with cold water, this salt yielded the following numbers on analysis:—

·2423 grm. gave ·3159 grm. carbonic acid, ·1204 grm. water, and ·1108 grm. silver.

These numbers agree well with the formula of silver amylacetate or œnanthylate.



$$C_2\begin{cases} C_5H_{11} \\ \underline{H_2} \\ O \\ O\,Ag \end{cases}$$

	Calculated.		Found.
C_7 . . .	84	35·44	35·56
H_{13} . . .	13	5·49	5·52
Ag . . .	108	45·57	45·72
O_2 . . .	32	13·50	13·20
	237	100·00	100·00

We have also examined the barium-salt, which is an amorphous soapy substance. Dried at 100° C., ·2715 grm. gave ·1599 grm. barium sulphate, corresponding to 34·62 per cent. of barium. Barium œnanthylate contains 34·69 per cent. of barium. We state our reasons below for believing amylacetic acid to be identical with œnanthylic acid.

In the foregoing pages we have confined ourselves, as far as possible, to the bare description of experimental results, avoiding any digression to the theoretical considerations which naturally forced themselves upon our attention. It now becomes necessary, however, to take a retrospect of our results, in order to assign to them their proper place amongst chemical phenomena, and to point out their possible bearing upon future investigation in the same direction. In doing this it will be most convenient to discuss the subject under two heads, viz. the considerations involved in the production of the carboketonic ethers derived from the duplication of the atom of acetic ether, and secondly, those suggested by the replacement of the hydrogen in the methyl of acetic ether by the alcohol radicals.

I. *Constitution and chemical relations of the ethers and ketones derived from the duplication of the atom of acetic ether.*

There is always a difficulty in assigning to an entirely new series of organic bodies their true position among other families, and this is more especially the case when, like the bodies now under consideration, they exhibit but few obvious relations to other series. It is therefore with some hesitation, in regard to the ultimate place that may be assigned to them, that we have ventured to consider these bodies as the ethers of peculiar acids, the latter compounded of the ketones and carbonic acid, the general formula of these acids being

$$C_4^{x}\left\{\begin{array}{l} H_3 \\ \hline O \\ \hline C_n H_{2n+1} \\ C_n H_{2n+1} \\ \hline O \\ O H \end{array}\right. = C_3^{viii}\left\{\begin{array}{l} C H_3 \\ O \\ \hline C_n H_{2n+1} \\ C_n H_{2n+1} \\ \hline O \\ O H \end{array}\right. = C_2^{vi}\left\{\begin{array}{l} C\left\{\begin{array}{l} C H_3 \\ O \end{array}\right. \\ C_n H_{2n+1} \\ C_n H_{2n+1} \\ \hline O \\ O H \end{array}\right.$$

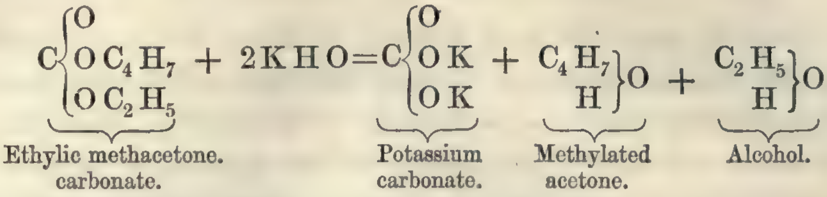
Looking only to the results of the action of caustic alkalies upon the ethylic ethers of these acids, and assuming a formula that will most readily explain this action, we arrive at the following very simple expression for these ethers,

$$C\left\{\begin{array}{l} O \\ O\, C_n H_{2n-1} \\ O\, C_2 H_5 \end{array}\right.$$

This is obviously the formula of carbonic ether,

$$C\left\{\begin{array}{l} O \\ O\, C_2 H_5 \\ O\, C_2 H_5 \end{array}\right.$$

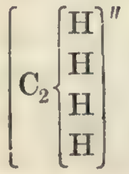
in which one atom of ethyl is replaced by the radical $C_n H_{2n-1}$, belonging to the allyl series; and the action of caustic alkalies upon ethylic methacetone carbonate, for instance, would be expressed as follows:—



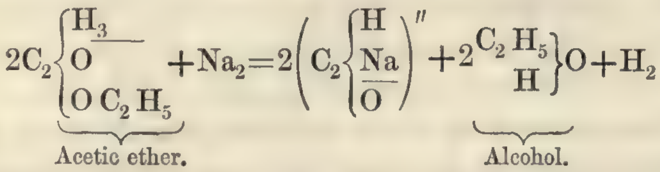
$$\underbrace{C\left\{\begin{array}{l}O\\ O\,C_4H_7\\ O\,C_2H_5\end{array}\right.}_{\text{Ethylic methacetone. carbonate.}} + 2KHO = \underbrace{C\left\{\begin{array}{l}O\\ O\,K\\ O\,K\end{array}\right.}_{\text{Potassium carbonate.}} + \underbrace{\left.\begin{array}{r}C_4H_7\\ H\end{array}\right\}O}_{\text{Methylated acetone.}} + \underbrace{\left.\begin{array}{r}C_2H_5\\ H\end{array}\right\}O}_{\text{Alcohol.}}$$

Notwithstanding the very simple expression which is thus given to this reaction, and which is in harmony with KANE's views of the constitution of acetone, we cannot adopt it without complicating other well-marked reactions in the ketone family, and ignoring the very palpable difference between the ketonic and alcoholic families. This alcoholic side of the ketone character, if we may be allowed the expression, supported as it is by the numerous compounds described by KANE, merits more attention than has hitherto been bestowed upon it, and on this account we have drawn attention to its bearings upon the bodies now under discussion, although we have not been able, in its present aspect, to avail ourselves of it in the interpretation of the reactions now under consideration.

In the rational formulæ which we have adopted for the carboketonic ethers, it is not difficult to trace the two original atoms of acetic ether which give rise to the new bodies. To take the production of ethylic methacetone carbonate as an example, it may be assumed that the action of sodium upon one atom of acetic ether converts the latter into a body equivalent to ethylene

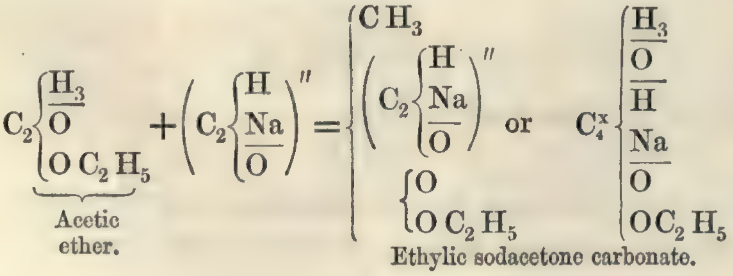


$$\left[C_2\left\{\begin{array}{l}H\\ H\\ H\\ H\end{array}\right\}''\right.$$



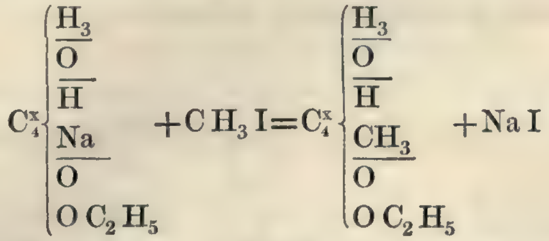
$$\underbrace{2C_2\left\{\begin{array}{l}\underline{H_3}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Acetic ether.}} + Na_2 = 2\left(C_2\left\{\begin{array}{l}H\\ \underline{Na}\\ O\end{array}\right.\right)'' + 2\underbrace{\left.\begin{array}{r}C_2H_5\\ H\end{array}\right\}}_{\text{Alcohol.}}O + H_2$$

and that this diatomic body then coalesces with an atom of unchanged acetic ether, linking together the two radicals of the latter, thus:



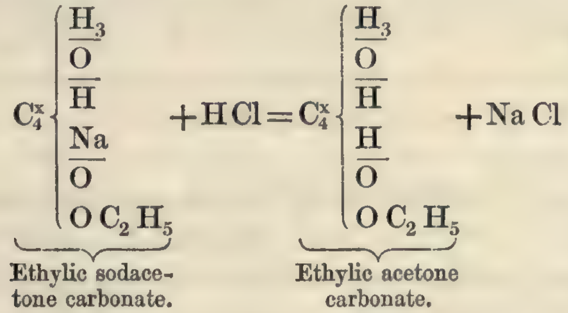
$$\underbrace{C_2\left\{\begin{array}{l}\underline{H_3}\\ O\\ O\,C_2H_5\end{array}\right.}_{\text{Acetic ether.}} + \left(C_2\left\{\begin{array}{l}H\\ \underline{Na}\\ O\end{array}\right.\right)'' = \underbrace{\left\{\begin{array}{l}C\,H_3\\ \left(C_2\left\{\begin{array}{l}H\\ \underline{Na}\\ O\end{array}\right.\right)''\\ \left\{\begin{array}{l}O\\ O\,C_2H_5\end{array}\right.\end{array}\right. \quad\text{or}\quad C_4^{x}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ H\\ \underline{Na}\\ O\\ OC_2H_5\end{array}\right.}_{\text{Ethylic sodacetone carbonate.}}$$

The exchange of sodium for methyl then converts ethylic sodacetone carbonate into ethylic methacetone carbonate.

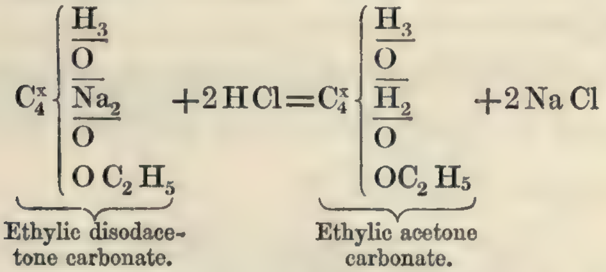


$$C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H\\Na\\\hline O\\O\,C_2H_5\end{array}\right. + CH_3I = C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H\\CH_3\\\hline O\\O\,C_2H_5\end{array}\right. + NaI$$

The constitution of the carboketonic ethers here developed indicates the existence of a compound in which the value of *n* in the above general formula$=0$. Such an ether would be produced by acting with hydrochloric acid upon either ethylic sodacetone carbonate or ethylic disodacetone carbonate.

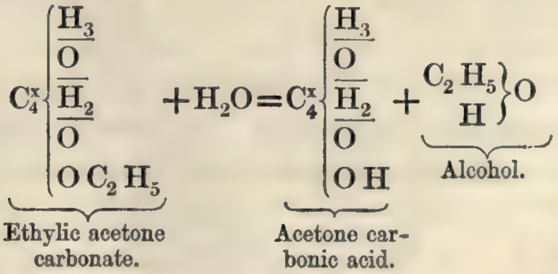


$$\underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H\\Na\\\hline O\\O\,C_2H_5\end{array}\right.}_{\text{Ethylic sodacetone carbonate.}} + HCl = \underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H\\H\\\hline O\\O\,C_2H_5\end{array}\right.}_{\text{Ethylic acetone carbonate.}} + NaCl$$



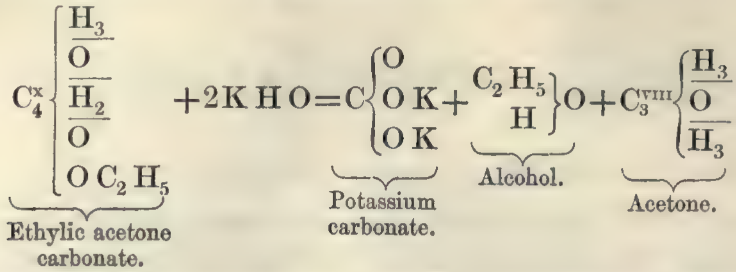
$$\underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline Na_2\\\hline O\\O\,C_2H_5\end{array}\right.}_{\text{Ethylic disodacetone carbonate.}} + 2HCl = \underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H_2\\\hline O\\OC_2H_5\end{array}\right.}_{\text{Ethylic acetone carbonate.}} + 2NaCl$$

The carboketonic ether thus indicated has actually been obtained by GEUTHER according to the first of the above equations, and is described by him, in the paper above alluded to, under the name *Di-methylene-carbonic-acid-ethylene ether*. In fact he appears to have also obtained, in a free state, the acid of the above ether which is formed when the latter is placed in contact with water, although he has not yet submitted it to investigation.



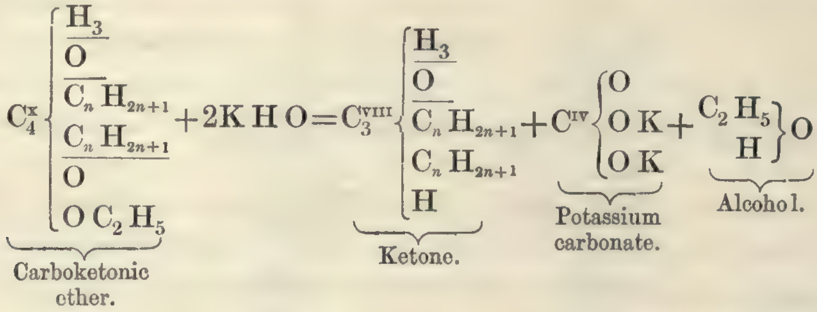
$$\underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H_2\\\hline O\\O\,C_2H_5\end{array}\right.}_{\text{Ethylic acetone carbonate.}} + H_2O = \underbrace{C_4^x\left\{\begin{array}{l}H_3\\\hline O\\\hline H_2\\\hline O\\O\,H\end{array}\right.}_{\text{Acetone carbonic acid.}} + \underbrace{\left.\begin{array}{c}C_2H_5\\H\end{array}\right\}O}_{\text{Alcohol.}}$$

Ethylic acetone carbonate, boiled with excess of baryta-water or alcoholic potash, ought to yield, in accordance with the homologous reactions, alcohol, a carbonate of the base, and acetone, according to the following equation:—



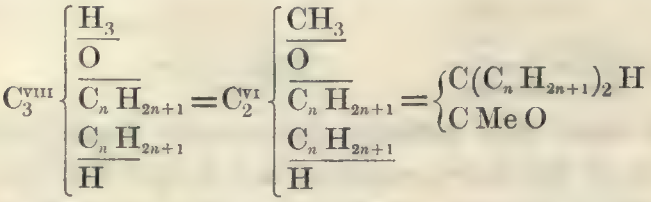
$$\underbrace{C_4^{\mathrm{x}}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ \underline{H_2}\\ \underline{O}\\ O\,C_2\,H_5\end{array}\right.}_{\text{Ethylic acetone carbonate.}} + 2K\,H\,O = \underbrace{C\left\{\begin{array}{l}O\\ O\,K\\ O\,K\end{array}\right.}_{\text{Potassium carbonate.}} + \underbrace{\left.\begin{array}{l}C_2\,H_5\\ H\end{array}\right\}}_{\text{Alcohol.}}O + \underbrace{C_3^{\mathrm{viii}}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ H_3\end{array}\right.}_{\text{Acetone.}}$$

The decomposition of the carboketonic ethers by caustic alkalies is readily traced by the use of the general formulæ above given; besides alcohol, a carbonate of the alkaline metal is produced, whilst a ketone containing three atoms less of carbon than the carboketonic ether is formed.



$$\underbrace{C_4^{\mathrm{x}}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_n\,H_{2n+1}\\ \underline{C_n\,H_{2n+1}}\\ O\\ O\,C_2\,H_5\end{array}\right.}_{\text{Carboketonic ether.}} + 2K\,H\,O = \underbrace{C_3^{\mathrm{viii}}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_n\,H_{2n+1}\\ C_n\,H_{2n+1}\\ H\end{array}\right.}_{\text{Ketone.}} + \underbrace{C^{\mathrm{iv}}\left\{\begin{array}{l}O\\ O\,K\\ O\,K\end{array}\right.}_{\text{Potassium carbonate.}} + \underbrace{\left.\begin{array}{l}C_2\,H_5\\ H\end{array}\right\}O}_{\text{Alcohol.}}$$

A closer inspection of this formula for ketones shows that it does not essentially differ from that usually adopted for these bodies, since it can readily be reduced to the radical type, thus:



$$C_3^{\mathrm{viii}}\left\{\begin{array}{l}\underline{H_3}\\ \underline{O}\\ C_n\,H_{2n+1}\\ \underline{C_n\,H_{2n+1}}\\ H\end{array}\right. = C_2^{\mathrm{vi}}\left\{\begin{array}{l}\underline{CH_3}\\ \underline{O}\\ C_n\,H_{2n+1}\\ \underline{C_n\,H_{2n+1}}\\ H\end{array}\right. = \left\{\begin{array}{l}C(C_n\,H_{2n+1})_2\,H\\ C\,Me\,O\end{array}\right.$$

The composition and mode of formation of the ketones described above, together with the general methods of forming these bodies previously known, indicate the existence of many isomeric compounds belonging to this family alone, without taking into consideration the metameric bodies in the aldehyde and allyl-alcohol series. The formula of acetone,

$$\left\{\begin{array}{l}C\,H_3\\ C\,Me\,O,\end{array}\right.$$

does not allow the conception of any isomer. The formula of the next higher ketone is equally incapable of isomeric modification, for the formulæ

$$\left\{\begin{array}{l}C\,H_3\\ C\,Et\,O\end{array}\right. \qquad \left\{\begin{array}{l}C\,Me\,H_2\\ C\,Me\,O\end{array}\right.$$

are only apparently isomeric. If reduced to the tetratomic carbon type, they both become C Me Et O. This is the formula of *methylated acetone*, described above, of *methylacetone* obtained by Fittig* in distilling lead acetate, and of *ethyl-acetyl* obtained by Freund† in acting upon acetyl chloride with zinc-ethyl. Unless physical causes of isomerism be assumed, there can be little doubt as to the identity of these three substances, the only difference known being in their boiling-points, which are as follow:—

		Barometer.
Methylated acetone	81° C.	about 760 millims.
Ethyl-acetyl	77°·5–78° C.	about 738 millims.
Methyl acetone	75°–77° C.	

The discrepancy between the first two ceases to be remarkable when the difference of pressure at which their boiling-points were determined is taken into account, and when it is remembered that our methylated acetone probably retained traces of dimethylated acetone which boils at 93°·5 C. Fittig does not give the boiling-point of his methyl acetone as an exact determination, remarking that "a more accurate determination of the boiling-point was obliged to be abandoned on account of the small amount of liquid available."

The origin of Fittig's methylacetone does not afford any satisfactory clue to its constitution, but the production of ethyl-acetyl and methylated acetone by synthetical processes, not only confirms the commonly received view of the constitution of the ketones, but also proves the identity of these two bodies. The formation of ethyl-acetyl by Freund's process shows that it consists of two bodies of the composition of the radicals indicated by the name, whilst the formula for methylated acetone, above given, if rightly interpreted, affirms the same thing.

$$\underbrace{\left\{\begin{matrix}C_2H_5\\ C_2H_3O\end{matrix}\right.}_{\text{Ethyl-acetyl.}} \qquad \underbrace{\left\{\begin{matrix}C\,Me\,H_2\\ C\,Me\,O\end{matrix}\right.}_{\text{Methylated acetone.}}$$

The presence of methyl in the so-called acetyl has been abundantly proved, consequently the chlorous radical is the same in both the above formulæ, whilst the formation of butyric acid, by the substitution of ethyl for hydrogen in the methyl of acetic acid, proves that ethylated methyl is identical with propyl, and that consequently methylated methyl is the same thing as ethyl, therefore the basylous radicals in the above formulæ are also identical.

Butyral, which is isomeric with methylated acetone, has been classed by Kekulé amongst the ketones, but we cannot agree with this classification, as, unlike a ketone, it yields on oxidation a fatty acid containing the same number of atoms of carbon, and it also reduces with facility ammoniacal solution of silver oxide; in fact Kekulé's own definition of a ketone excludes it completely from this class of bodies. Butyral does not appear to be identical with the butyraldehyde obtained by the oxidation of protein bodies, for the first does not, according to CHANCEL, form a definite compound with ammonia, whilst the second does. The two following formulæ possibly express the nature of this isomerism:—

---

* Ann. der Ch. und Pharm. cx. 17.

† *Ibid.* cxviii. 1.

$$\text{Butyral} \; . \; . \; . \; . \; . \; . \; . \quad \left\{\begin{matrix}\mathrm{C\,Et\,H_2} \\ \mathrm{C\,O\,H}\end{matrix}\right.$$

$$\text{Butyraldehyde} \; . \; . \quad . \quad \left\{\begin{matrix}\mathrm{C\,Me_2\,H} \\ \mathrm{C\,O\,H}\end{matrix}\right.$$

If this hypothesis be correct, the first ought to yield on oxidation normal butyric acid, and the second dimethacetic acid.

When we ascend the ketonic series one step higher, isomerism becomes possible, and the ketonic formula $C_5\,H_{10}O$ is susceptible of the three following isomeric modifications:—

$$\begin{matrix} \text{I.} & \qquad & \text{II.} & \qquad & \text{III.} \\ \left\{\begin{matrix}\mathrm{C\,Et\,H_2} \\ \mathrm{C\,Me\,O}\end{matrix}\right. & & \left\{\begin{matrix}\mathrm{C\,Me_2\,H} \\ \mathrm{C\,Me\,O}\end{matrix}\right. & & \left\{\begin{matrix}\mathrm{C\,Me\,H_2} \\ \mathrm{C\,Et\,O}\end{matrix}\right. \end{matrix}$$

At first sight it would appear that two other isomers would be produced by the introduction of propyl ($\mathrm{C\,Et\,H_2}$) and isopropyl ($\mathrm{C\,Me_2\,H}$), thus $\left\{\begin{matrix}\mathrm{C\,H_3} \\ \mathrm{C\,Pr\,O}\end{matrix}\right.$ and $\left\{\begin{matrix}\mathrm{C\,H_3} \\ \mathrm{C\,Pr\beta\,O}\end{matrix}\right.$; but a closer inspection of these formulæ shows the first to be identical with No. I. and the second with No. II. Thus, reduced to the carbonic-acid type, these formulæ become respectively

$$\begin{matrix} \text{I.} & \qquad\qquad & \text{II.} \\ \mathrm{C\,Pr\,Me\,O} & & \mathrm{C\,Pr\beta\,Me\,O} \end{matrix}$$

All three isomers are now known. The first of the above formulæ is that of ethylated acetone described above, which readily forms a crystalline compound with sodium bisulphite. The second is that of dimethylated acetone, which we believe to be identical with the body obtained by FITTIG* in distilling lead acetate, and to which he gave the name ethyl acetone. Both bodies form crystalline compounds with sodium bisulphite. The boiling-point of dimethylated acetone is 93°·5 C. FITTIG states that ethyl acetone boils between 90° and 95°. The only discrepancy between the two compounds is in their specific gravities, which are as follow:—

Dimethylated acetone	·8099 at 13° C.
Ethyl acetone	·842 at 19° C.

This discrepancy may perhaps be explained by the fact that FITTIG'S ketone yielded on analysis 0·6 per cent. too much carbon, and 0·4 per cent. too little hydrogen, which would indicate that it still contained dumasin, from which it had been approximately separated by fractional distillation.

The name which FITTIG has applied to his ketone of the above composition implies that he regarded it as ethylated acetone, but the boiling-point of the latter (101° C.) precludes this supposition (see remarks about these boiling-points below).

The third of the above formulæ is that of FREUND'S† ethyl-propionyl prepared by the action of zinc ethyl upon propionyl chloride. This body boils at 101° C. like ethylated acetone, but, unlike the latter, does not form a crystalline compound with sodium bisulphite. The origin of MORLEY'S propione*, obtained by the distillation of barium propionate, renders its identity with ethyl-propionyl almost certain. Its boiling-point, 100° C., is nearly the same, and, like ethyl-propionyl, it also, as FREUND has proved, refuses to form a crystalline compound with sodium bisulphite.

---

* Ann. der Ch. und Pharm. cx. 17.

† *Ibid.* cxviii. 1.

There are still two other compounds of this formula which have been sometimes classed as ketones, but respecting which evidence is still wanting as to whether they belong to the ketone or aldehyde family. These are LIMPRICHT and USLAR'S propione†, which boils at 110° C., and methyl-butyral‡, which boils at 111° C. The first forms a crystalline compound with sodium bisulphite, but it is not known whether or not it reduces ammoniacal solution of silver oxide. The behaviour of the second with either of these reagents is unknown.

The seven-carbon ketones to which diethylated acetone belongs, are capable of more numerous modifications, of which however only two are known, viz.—

$$\text{Butyrone} \;.\;.\;.\;.\;.\;.\; \begin{cases} \mathrm{C\,Et\,H_2} \\ \mathrm{C\,Pr\,O} \end{cases}$$

$$\text{Diethylated acetone} \;.\;.\;.\; \begin{cases} \mathrm{C\,Et_2\,H} \\ \mathrm{C\,Me\,O} \end{cases}$$

The isomerism of these bodies is evident from their origin, and from the difference of 6° in their boiling-points, butyrone boiling at 144° C., whilst diethylated acetone boils at 137°–139°C. The rise in boiling-point by the successive replacement of the hydrogen of methyl by alcohol radicals affords a valuable clue to the constitution of numerons organic compounds, and attention has recently been called to this subject by KOLBE§, who has shown that the successive replacement by alcohol radicals of the three atoms of hydrogen in ammonia and in the methyl of methylic alcohol is attended with very different results as regards elevation of boiling-point; thus the addition of $\mathrm{C\,H_2}$ to aniline $\left(\mathrm{N}\begin{cases}\mathrm{C_6\,H_5} \\ \mathrm{H} \\ \mathrm{H}\end{cases}\right)$ with the production of toluidine $\left(\mathrm{N}\begin{cases}\mathrm{C_7\,H_7} \\ \mathrm{H} \\ \mathrm{H}\end{cases}\right)$ raises the boiling-point about 19° C.; but if the addition of $\mathrm{C\,H_2}$ to aniline converts the latter into methyl-aniline $\left(\mathrm{N}\begin{cases}\mathrm{C_6\,H_5} \\ \mathrm{C\,H_3} \\ \mathrm{H}\end{cases}\right)$, then the boiling-point rises only 10°, whilst the replacement of the third atom of hydrogen appears to be attended with a rise of only about 5° C. This observation, so far as the existence of the difference described is concerned, receives considerable support from the boiling-points of the ketones mentioned above, although the actual numerical expression of this difference does not coincide with that given by KOLBE. Thus acetone boils at about 55° C., and methylated acetone at 81° C., the difference being 26° C.; and a comparison of the two formulæ,

---

* Ann. der Ch. und Pharm. lxxviii. 187.

† *Ibid.* xciv. 327.

‡ *Ibid.* lii. 295.

§ *Ibid.* cxxxii. 112.

$$\underbrace{\begin{cases}\mathrm{C\,H_3}\\ \mathrm{C\,Me\,O}\end{cases}}_{\text{Acetone.}} \qquad \underbrace{\begin{cases}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,Me\,O}\end{cases}}_{\text{Methylated acetone.}}$$

shows that acetone is converted into methylated acetone by the substitution of methyl for the *first* atom of hydrogen in methyl. Dimethylated acetone,

$$\begin{cases}\mathrm{C\,Me_2\,H}\\ \mathrm{C\,Me\,O},\end{cases}$$

boils at 93°·5, which is only 12°·5 higher than methylated acetone. An inspection of the formula of this body shows that it is derived from methylated acetone by the substitution of methyl for the *second* atom of hydrogen in the methyl of acetone. Again, ethylated acetone is derived from acetone by the substitution of ethyl for the first atom of hydrogen in the methyl of acetone, and its boiling-point is 101° or 23°×2=46° higher than that of acetone, whilst the boiling-point of diethylated acetone is 138° or 18°·5×2=37° above that of ethylated acetone. In all cases of isomerism it may be safely asserted that the body containing the fewest atoms of hydrogen replaced by an alcohol radical will boil at the highest temperature.

This is clearly seen in the following examples:—

	Name.	Formula.	Boiling-point.
Isomeric . .	Butyral	$\left\{\begin{matrix}\mathrm{C\,Et\,H_2}\\ \mathrm{C\,H\,O}\end{matrix}\right\}$ . . .	95° C.
	Methylated acetone . . .	$\left\{\begin{matrix}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,Me\,O}\end{matrix}\right\}$ . . .	81° C.

Isomeric . .	Methyl-butyral	$\left\{\begin{matrix}\mathrm{C\,Pr\,H_2}\\ \mathrm{C\,H\,O}\end{matrix}\right\}$ . . .	111° C.
	Ethylated acetone . . .	$\left\{\begin{matrix}\mathrm{C\,Et\,H_2}\\ \mathrm{C\,Me\,O}\end{matrix}\right\}$ . . .	101° C.
	Ethyl-propionyl	$\left\{\begin{matrix}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,Et\,O}\end{matrix}\right\}$ . . .	101° C.
	Dimethylated acetone . .	$\left\{\begin{matrix}\mathrm{C\,Me_2\,H}\\ \mathrm{C\,Me\,O}\end{matrix}\right\}$ . . .	93°·5 C.

	Name.	Formula.	Boiling-point.
Isomeric	Butyrone	$\left\{\begin{matrix} C\,Et\,H_2 \\ C\,Pr\,O \end{matrix}\right\}$	144° C.
	Diethylated acetone	$\left\{\begin{matrix} C\,Et_2\,H \\ C\,Me\,O \end{matrix}\right\}$	138° C.

The carboketonic ethers show in a very remarkable manner the boiling-point values of different atoms of hydrogen, whilst the two isomeric bodies of this series also exemplify what has just been stated regarding the inference of constitution from the boiling-point. Reduced to the radical type, these bodies may be thus tabulated:—

Name.	Formula.	Boiling-point.
Ethylic acetone carbonate	$\left\{\begin{matrix} C(C\,Me\,O)H_2 \\ C\,O\,Eto* \end{matrix}\right\}$	176° C.
Ethylic methacetone carbonate	$\left\{\begin{matrix} C(C\,Me\,O)Me\,H \\ C\,O\,Eto \end{matrix}\right\}$	184° C.
Ethylic dimethacetone carbonate	$\left\{\begin{matrix} C(C\,Me\,O)Me_2 \\ C\,O\,Eto \end{matrix}\right\}$	184° C.
Ethylic ethacetone carbonate	$\left\{\begin{matrix} C(C\,Me\,O)Et\,H \\ C\,O\,Eto \end{matrix}\right\}$	195° C.
Ethylic diethacetone carbonate	$\left\{\begin{matrix} C(C\,Me\,O)Et_2 \\ C\,O\,Eto \end{matrix}\right\}$	211° C.

It will be seen from these formulæ that the lowest of the carboketonic ethers has already one atom of methylic hydrogen replaced by the radical acetyl ($C\,Me\,O$), consequently the further substitution of methyl and ethyl takes effect upon the second and third atoms of methylic hydrogen. When in the formation of ethylic methacetone carbonate the second atom of hydrogen becomes replaced by methyl, the boiling-point rises only 8° C.; but when the third atom of hydrogen is in like manner exchanged for methyl the boiling-point is not appreciably affected, ethylic methacetone carbonate and ethylic dimethacetone carbonate both boiling at the same temperature.

The introduction of ethyl in the place of the second atom of hydrogen, in passing from ethylic acetone carbonate to ethylic ethacetone carbonate, raises the boiling-point 19° C., or 9°·5 for each addition of $C\,H_2$. Ethacetone carbonate contains $C\,H_2$ more than methacetone carbonate, and the addition is also here made to the group occupying the place of the second atom of hydrogen: in this case the addition of $C\,H_2$ is also attended by a rise of only 11° in the point of ebullition. Finally, the conversion of ethylic ethacetone carbonate into ethylic diethacetone carbonate, unlike the corresponding change in the methyl compounds, is attended with a marked though small rise of boiling-point equivalent to 8° C. for each $C\,H_2$ added.

---

* Eto = Ethoxyl = ($C_2\,H_5\,O$).

Thus it is evident that the replacement of each of the three atoms of methylic hydrogen by the same alcohol radical is attended with a different result as regards the elevation of boiling-point, and that the rise in the temperature of ebullition becomes markedly less as each atom of typical hydrogen is successively replaced, although the absolute thermal values of each of the three atoms depend upon functions which have not yet been discovered.

II. *Constitution of the Fatty Acids.*

There is perhaps no series of organic compounds which has been the subject of such numerous investigations and theoretical speculations as that of the fatty acids; nevertheless the synthesis of several of these acids, by a method of general application described in the foregoing pages, whilst confirming some previous views regarding the constitution of these bodies, has opened a path into their basylous constituent which had not previously been explored, and has disclosed the existence of vast numbers of isomers, which now require only the expenditure of time and labour for their production.

Amongst the investigations and theoretical views above alluded to, we would especially call attention to those of KOLBE and FRANKLAND[*], and of DUMAS[†], which proved the existence of methyl in acetic acid, and of other alcohol radicals in the higher homologues of that acid; to FRANKLAND'S view of the constitution of the alcohol radicals themselves, a short abstract of which appeared in the British Association Reports for 1855, Trans. of Sect. p. 62[‡]; and of KOLBE and FRANKLAND[§], who in the year 1857 proposed the derivation of these and a large number of other organic compounds from the carbonic acid or tetratomic carbon type; and finally, to a recent paper by KOLBE[||], in which he predicts the discovery of dimethacetic acid, and of other similarly constituted acids.

We conceive each fatty acid to be formed by the union of a chlorous and a basylous radical. In all acids higher than the formic, these radicals are held together by one of the atomicities of a carbon atom in each, as expressed in the following formulæ of acetic acid:—

---

[*] Memoirs and Proceedings of the Chemical Society, vol. iii. p. 386, and Ann. der Ch. und Pharm. lxv. s. 288; lxix. s. 258.

[†] Comptes Rendus, xxv. 383.

[‡] As this abstract does not appear to be generally known, we here copy it from the report in question:—

"These remarkable reactions lead the author to anticipate that zincethyl will prove in the hands of chemists a new and valuable means of research; for it is evident from its reactions that it will be capable of replacing electro-negative elements in organic or inorganic compounds by ethyl; a kind of replacement which has never yet been attempted, but which the author anticipates will enable him to build up organic compounds from inorganic ones, and ascend the homologous series of organic bodies; by replacing, for instance, the hydrogen in a methylic compound by chlorine or iodine, and then acting upon this product of substitution by zincethyl or zincmethyl, the author believes that compounds higher in the series will be obtained, since he regards the higher homologues of methyl and its compounds as derived from the latter radical by the successive replacement of hydrogen by methyl."

[§] Ann. der Ch. und Pharm. Bd. ci. s. 260.

[||] Zeitschrift f. Ch. u. Pharm. 1864, s. 30.

$$C_2^{\mathrm{VI}}\left\{\begin{matrix}\underline{H_3}\\ O\\ Ho\,^{*}\end{matrix}\right. \quad \text{or} \quad \left\{\begin{matrix}C\,H_3\\ C\,O\,Ho\end{matrix}\right.$$

Inasmuch, however, as formic acid contains only one carbon radical, the simple basylous radical hydrogen is retained in combination with the compound chlorous radical by the fourth atomicity of the carbon atom in the latter:

$$\overset{H}{C}\left\{\begin{matrix}O\\ Ho\end{matrix}\right. \quad \text{or} \quad \left\{\begin{matrix}H\\ C\,O\,Ho\end{matrix}\right.$$

This difference in the constitution of formic acid, as compared with that of the higher members of the same family, makes itself felt in numerous well known abnormal reactions.

The chlorous radical of the fatty acids remains unchanged throughout the entire series, and it is to alterations made in the basylous radical that the separate terms of the series owe their formation.

An inspection of the above formula of acetic acid shows that its basylous radical methyl contains three single atoms of hydrogen combined with a tetratomic atom of carbon; and we have proved, by the production of the synthesized acids above described, that two of these atoms of hydrogen are replaceable by the alcohol radicals, the synthesized acids standing, with regard to acetic acid, in the relations represented by the following formulæ:—

$$\underbrace{\left\{\begin{matrix}C\,H_3\\ C\,O\,Ho\end{matrix}\right.}_{\text{Acetic acid.}} \qquad \underbrace{\left\{\begin{matrix}C\,Et\,H_2\\ C\,O\,Ho\end{matrix}\right.}_{\text{Ethacetic or butyric acid.}} \qquad \underbrace{\left\{\begin{matrix}C\,Me_2\,H\\ C\,O\,Ho\end{matrix}\right.}_{\text{Dimethacetic acid.}}$$

$$\underbrace{\left\{\begin{matrix}C\,Et_2\,H\\ C\,O\,Ho\end{matrix}\right.}_{\text{Diethacetic acid.}} \qquad \underbrace{\left\{\begin{matrix}C\,Ay\,H_2\\ C\,O\,Ho\end{matrix}\right.}_{\text{Amylacetic or œnanthylic acid.}}$$

Although we have not as yet obtained with certainty acids originating from the replacement of more than two of the atoms of hydrogen in the methyl of acetic acid by alcohol radicals, yet there can be little doubt that the third atom admits of a similar substitution; and we have, in fact, obtained indications of the formation of acids depending upon this threefold replacement—an operation which, if carried out with amyl, would obviously produce triamyl-acetic acid, possessing the composition of margaric acid:

$$C_{17}\,H_{34}\,O_2=\left\{\begin{matrix}C\,Ay_3\\ C\,O\,Ho\end{matrix}\right.$$

---

[*] Ho = hydroxyl or peroxide of hydrogen = HO.

It is unnecessary at present to follow the development of this reaction further; but it is evident, from what has been already done, that by a proper selection of the three radicals put into the place of the methylic hydrogen, any fatty acid, from the margaric downwards, can be produced without difficulty.

In order to understand the relations between the synthesized and the natural fatty acids, it is necessary to remember the constitution of the latter as revealed in their production from the cyanides of the alcohol radicals; these radicals, of which the cyanides have been so employed, must consist of methyl in which not more than one atom of hydrogen has been replaced, since the alcohols containing them yield by suitable oxidation the corresponding fatty acids; whereas it has been shown by FRIEDEL* that secondary alcohols, such as isopropylic alcohol, in which *two* atoms of methylic hydrogen have been replaced, yield, under the same conditions, ketones instead of acids. Hence the molecules of the normal alcohol radicals must possess the following constitution:—

Methyl . . . . $\left\{\begin{matrix}\mathrm{C\,H_3}\\ \mathrm{C\,H_3}\end{matrix}\right.$

Ethyl or methylated methyl . . . . $\left\{\begin{matrix}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,Me\,H_2}\end{matrix}\right.$

Propyl or ethylated methyl . . . . $\left\{\begin{matrix}\mathrm{C\,Et\,H_2}\\ \mathrm{C\,Et\,H_2}\end{matrix}\right.$

Butyl or propylated methyl . . . . $\left\{\begin{matrix}\mathrm{C\,Pr\,H_2}\\ \mathrm{C\,Pr\,H_2}\end{matrix}\right.$

Amyl or butylated methyl . . . . $\left\{\begin{matrix}\mathrm{C\,Bu\,H_2}\\ \mathrm{C\,Bu\,H_2}\end{matrix}\right.$

&c. &c.

and hence when the cyanides of these radicals are boiled with caustic alkalies, they yield acids containing as their basylous constituent, the normal alcohol radicals which were present in the cyanides; thus ethylic cyanide yields potassium propionate—

$$\underbrace{\left\{\begin{matrix}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,N}\end{matrix}\right.}_{\text{Ethylic cyanide.}}+\mathrm{K\,H\,O}+\mathrm{H_2O}=\underbrace{\left\{\begin{matrix}\mathrm{C\,Me\,H_2}\\ \mathrm{C\,O\,KO}\end{matrix}\right.}_{\text{Potassium propionate.}}+\mathrm{N}\left\{\begin{matrix}\mathrm{H}\\ \mathrm{H}\\ \mathrm{H}\end{matrix}\right.$$

An inspection of the above formula for potassium propionate shows that propionic acid is incapable of isomerism from any change of radicals; and, inasmuch as ethyl is simply methylated methyl, it follows that methacetic acid, when obtained by the substitution of one atom of hydrogen in acetic acid by one of methyl, must be identical with propionic acid, which, with acetic acid, can have no isomer depending on a difference of radicals. When, however, we ascend the next step of the series, we find that butyric acid is capable of two, and only two isomeric modifications, viz.,

---

* Bulletin de la Soc. Chimique, 1863, p. 247.

$$\underbrace{\begin{cases}\mathrm{C\,Et\,H_2}\\ \mathrm{C\,O\,Ho}\end{cases}}_{\text{Ethacetic acid.}} \text{ and } \underbrace{\begin{cases}\mathrm{C\,Me_2\,H}\\ \mathrm{C\,O\,Ho}\end{cases}}_{\text{Dimethacetic acid.}}$$

Both these acids have now been synthetically produced, and the first must be identical with butyric acid, since they both contain ethylated methyl as their basylous radical—a conclusion which is in perfect harmony with experimented facts, for we have shown above that butyric acid and ethacetic acid are undistinguishable from each other, whilst methacetic acid differs in odour and in the crystalline form of its silver-salt.

Ascending now to caproic acid, the number of possible isomers is augmented to eight, this being in fact the number of possible metameric modifications of the basylous radical of caproic acid—amyl, viz.:—

$$\overset{\text{I.}}{\mathrm{C}\begin{cases}\mathrm{Bu}\\ \mathrm{H}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{II.}}{\mathrm{C}\begin{cases}\mathrm{Pr}\\ \mathrm{Me}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{III.}}{\mathrm{C}\begin{cases}\mathrm{Et}\\ \mathrm{Et}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{IV.}}{\mathrm{C}\begin{cases}\mathrm{Et}\\ \mathrm{Me}\\ \mathrm{Me}\end{cases}}$$

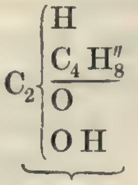
$$\overset{\text{V.}}{\mathrm{C}\begin{cases}\mathrm{(C\,Et\,Me\,H)}\\ \mathrm{H}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{VI.}}{\mathrm{C}\begin{cases}\mathrm{C\,Me_3}\\ \mathrm{H}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{VII.}}{\mathrm{C}\begin{cases}\mathrm{C\,(C\,Me_2\,H)H_2}\\ \mathrm{H}\\ \mathrm{H}\end{cases}} \qquad \overset{\text{VIII}}{\mathrm{C}\begin{cases}\mathrm{C\,Me_2\,H}\\ \mathrm{Me}\\ \mathrm{H}\end{cases}}$$

No. I. is normal amyl or butylated methyl; Nos. II., III., and IV. are obvious isomers, whilst the remainder owe their differences to the metameric modification of the radicals butyl and propyl contained in Nos. I. and II.

Of the isomeric acids, those containing the radicals Nos. I. and III. are the only ones known. The first is the caproic acid obtained by the action of potash upon amyl cyanide, and which is probably identical with the caproic acid obtained from cocoa-nut oil; whilst the second is diethacetic acid obtained as above described, and which differs from caproic acid in its odour, in the boiling-point of its ether (which is 11° C. lower than caproic ether), in the specific gravity of its ether, and in the crystalline form and solubility of its silver-salt.

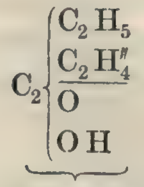
Œnanthylic acid admits of still more numerous isomeric modifications, of which only one is at present known with certainty, since, for the reasons above given, we believe amylacetic acid to be identical with the acid that would be obtained by the action of potash upon heptyl cyanide, and probably also with that obtained from castor oil and other similar sources.

Now, inasmuch as the acids obtained from the cyanides appear to be identical with the natural or non-synthesized acids of the same atomic weights, and as the alcohol radicals in these cyanides are normal radicals, that is, methyls in which only one atom of hydrogen has been replaced, it is highly probable that all the non-synthesized acids contain normal radicals with *two* atoms of unreplaced hydrogen, just as the natural acids of the acrylic series contain, as we have proved for a large majority of them *, the largest possible number of atoms of unreplaced hydrogen, which is one atom, thus differing from the synthesized acids of the same series which contain no unreplaced hydrogen, as seen for instance in pyroterebic acid and its synthesized isomer ethyl-crotonic acid.



$$\underbrace{C_2\left\{\begin{array}{l} H \\ \underline{C_4 H_8''} \\ O \\ O\,H \end{array}\right.}$$

Pyroterebic acid.



$$\underbrace{C_2\left\{\begin{array}{l} C_2 H_5 \\ \underline{C_2 H_4''} \\ O \\ O\,H \end{array}\right.}$$

Ethyl-crotonic acid.

This remarkable peculiarity in the constitution of the radicals of natural or analytically obtained organic compounds, must be the expression of some general law regulating the formation of those compounds, and which cannot much longer elude detection.

Intimately connected with isomerism in the fatty acids is the like phenomenon in the alcohols which has recently been remarked by KOLBE † and by FRIEDEL ‡; in fact the synthesis of the carboketonic ethers and of the fatty acids lays open a direct path, through the beautiful reactions either of MENDIUS or FRIEDEL, to corresponding alcohols.

In conclusion, there can be no doubt that the reaction which forms the subject of this paper is capable of a very wide extension, and that by its means we shall be able to ascend many of the well-recognized homologous series. In future communications we hope to have the honour of laying before the Royal Society the results of its extension to the alcohols and ethers, and to the benzoic series of ethereal salts.

* Journ. Chem. Soc. vol. xviii. p. 147.

† Zeitschrift Ch. u. Pharm. Bd. v. 687.

‡ Bulletin de la Soc. Chimique, 1863, p. 247.

IV. *On the Fossil Mammals of Australia.*—Part II. *Description of an almost entire Skull of the* Thylacoleo carnifex, Owen, *from a freshwater deposit, Darling Downs, Queensland.* *By Professor* Owen, *F.R.S., &c.*

Received June 8,—Read June 15, 1865.

I have been favoured by Edward Hill, Esq., of Sydney, New South Wales, through the kind offices of his brother-in-law Sir Daniel Cooper, Bart., with a small collection of fossil remains from that part of the freshwater deposits of Darling Downs through which the river Condamine has cut its bed.

Among these fossils were parts of a broken skull, at once recognizable, by its carnassial teeth, as belonging to the same large carnivorous marsupial as afforded the subject of Part I. of the present series of papers.

On readjusting these fragments, I was gratified to find that they formed a more perfect skull than the one which first indicated the genus and species, and not only confirmed the marsupial character of the fossil, but supplied particulars of much value in determining the affinities of *Thylacoleo* in the marsupial series.

In previously reconstructing so much of the skull of the *Thylacoleo* as is figured in Plate XI. of the 'Philosophical Transactions' for 1859, I had, for the facial portion there preserved, only the guide of a small surface on the nasal process of a detached maxillary bone which fitted to about half an inch of the fractured surface of the fore part of the cranium. I was glad, therefore, to have the accuracy of that 'fit' confirmed by the more perfect state of the skull here described.

In comparing the upper carnassial tooth of *Thylacoleo* with that of *Felis* in my former paper, I had to regret that a fracture, with some loss of the tooth in the marsupial carnivore, prevented the precise determination of its degree of difference from that of the placental feline in regard to the "tubercular" part of the carnassial; but a close inspection of the tooth in the fossil led me to infer that "little more than the enamel" had been broken away (p. 311). The perfect condition of both right and left carnassials at the fore part of the crown in the present instance (Plate III. p_4) enables me to state that, in the place of the tubercle, there is only a low vertical ridge of enamel, about a line in breadth, without any additional inner root at the fore part of the tooth: the large carnassial of *Thylacoleo* consists exclusively of the "blade." This is more worn than in the original specimen described. A smooth and polished surface is exposed by attrition, sloping from within downward and outward, and meeting the inwardly bent outer enamelled surface at an angle of about 50°. The worn surface is deeper at the fore and hind parts of the tooth than at the middle, agreeably with the antero-posterior concavity of the outer surface. The hindmost part of the worn surface, which is 4 lines across, slopes rather outwardly from the rest, at a low angle defined by a linear boundary. I conclude that this surface is formed by the attrition of the small tooth succeeding the carnassial in the lower jaw, and marked *m* 1, fig. 3, Plate XI. of the former paper. The more extended anterior surface indicates that the lower carnassials pass within the upper ones when the mouth is shut. The whole abraded surface shows a play of the teeth for trenchant action, like that of the blades of shears, in a more striking degree than in the carnassials of Felines. The fore part of the carnassial, here 7 lines in breadth at the base of the crown, is formed by a ridge of enamel, acquiring, as it approaches the working surface, a line in breadth; from this the crown quickly expands to its greatest breadth, which is defined by a similar vertical ridge on both the outer and inner sides of the tooth. The enamel tract between the anterior and outer ridges is convex; that between the anterior and inner ridges is flat. The outer surface of the enamel behind the ridge shows several slight linear vertical impressions, between which the enamel slightly bulges out, at the basal part of the crown, the grooves subsiding halfway toward the trenchant border; the enamel is also finely wrinkled. The vertical extent of the enamel decreases from the fore to the hind end of the crown. I have nothing more to add from this second specimen to the description of the upper carnassial of *Thylacoleo* given at p. 311 of my former paper. The breadth of the palate between the fore parts of the carnassials is 3 inches 5 lines, and between the hind parts 3 inches 10 lines; showing the slight convergence of the antero-posteriorly extended crowns of the carnassials anteriorly.

In the portion of upper jaw first described, the fore part had been broken away immediately in front of the alveolus of the carnassial tooth; but enough of the bone on the outer side of the socket remained to determine a differential character between *Felis* and *Thylacoleo* in favour of the marsupiality of the latter. From the state of the first specimen I could only say that the suborbital or antorbital canal "must open some way in advance of the socket of the penultimate tooth, as it does in *Sarcophilus*" (p. 312). The present specimen shows that the anterior opening of the canal (Plate III. $_{21}$) is about 3 lines in advance of the alveolus of that tooth (here the carnassial, p_4), 10 lines above the alveolar border of the maxillary, and 6 lines behind the maxillo-premaxillary suture. The foramen is vertically elliptical, 3½ lines in long diameter, and 2½ in the opposite diameter. The corresponding foramen in *Felis Leo* may be 10 lines in long diameter and 6 lines in short diameter. This difference indicates the minor extent of sensitive surface and (vibrissal ?) appendages in *Thylacoleo* as compared with *Felis*, and corresponds with the singular relative shortness of the muzzle in *Thylacoleo*, which the present instructive fossil exemplifies.

In this specimen the right occipital condyle is entire: it forms outwardly a strong oblique convexity, broadest above, contracting as it bends round the outside of the foramen magnum forward and inward; toward the foramen the condyle is slightly concave lengthwise (Plate III. $_2$). The lower ends of the condyles are about 5 lines apart, the upper ends 1 inch 3 lines. The foramen magnum is 1 inch in transverse, and 7½ lines in vertical diameter: it looks backward and a little downward. About 4 lines in advance of the foramen the basioccipital (Plate III. $_1$) begins to show a median longitudinal ridge, formed, or left apparently, by a pair of smooth excavations of this part of the under surface of the basi-occipito-sphenoid, the anterior half of which is bounded externally by the thick obtuse ridges developed from the sides of the basisphenoid (*ib.* $_5$). The depressions and dividing ridge are present, but more feebly marked in *Felis*; the basisphenoida ridges, which prolong backward the pterygoid walls (*ib.* $_{24}$) of the post-narial canal, are not developed in *Felis*: the breadth of the basis cranii between the tympanics is much greater in *Thylacoleo* than in *Felis*. The suture between the basioccipital and basisphenoid is obliterated. The pterygoids (*ib.* $_{24}$) are of great length; their bases almost meet beneath the presphenoid, but gradually diverge as they extend backward, uniting suturally with the sides of the basisphenoid as far back as the low thick ridges (*ib.* $_5$), which are the sole representatives of the "pterygoid processes" of the sphenoid. The bodies of the cranial vertebræ describe the same curve, convex lengthwise downward, as in the first specimen. The basisphenoid anterior to the median ridge is gently concave transversely, and this concavity becomes deepened by the junction of the pterygoids, as the centrums advance, the pterygoid plates arching from the junction downward and outward, to form the sides of the posterior continuation of the bony nostrils or respiratory passage. The conformity in this part of the cranial structure of *Thylacoleo* with that in *Thylacinus* (Phil. Trans. 1859, Pl. XIV. fig. 3) is very close.

The paroccipital (Plates II. & III. $_4$) is broken, but seems not to have extended far below the level of the occipital condyle; it articulates externally with the mastoid ($_8$), which is not coextensive therewith vertically. Together they form a low, thick, obtuse, rough, subtrihedral pyramid, with the base downward and the outer side excavated.

The median vertical superoccipital ridge (Plate IV. fig. 2, $_3$) and the lateral depressions are better developed in the present specimen, with the more abraded carnassial teeth, than in the one first described; indicating the longer subjection of the bone to the action of the nuchal muscles.

The cranial nervures and vascular foramina are as in the first specimen, with which also the tympanic (Plate III. $_{28}$) agrees in its small size and relative position.

Nearly the whole of the articular surface for the mandibular ramus (Plate III. $_{27}$) is preserved on the right side of the present specimen; it is 1 inch 6 lines in transverse, and nearly 1 inch in antero-posterior extent; concave transversely, moderately convex from behind forward at its horizontal part; this facet changing or deepening to the concave only, where it is continued upon the post-glenoid plate: this is deeper than in the Lion, and much thicker; it is on the same transverse line as the tympanic, and is divided by the narrow fissure below the meatus auditorius externus from the mastoid.

There was sufficient of the articular surface in the first-described fossil to show that it had a greater antero-posterior extent than in *Felis*, with some minor characters of difference in which it more resembled that part in the Ursine Dasyure. So much of this significant part of the skull being preserved in the present fossil as is formed by the zygomatic process of the squamosal demonstrates the wide difference from the semi-cylindrical transverse canal characteristic of the ginglymoid joint of the lower jaw in placental *Carnivora*. The surface, though of great transverse extent, was probably carried out further in that direction by the malar bone (to judge by the analogy of the *Dasyurus*, Philosophical Transactions, 1859, Plate XIV. fig. 2); but this part of the zygoma has been broken away. There is a striking similarity, indeed, in the kind of mutilation which the fossil skull from the freshwater deposits at Colungoolac (*ib.* p. 310), and that from the same formations channelled by the Condamine, has undergone. The occipital condyles, zygomatic arches, and postorbital processes have suffered, differing only in the degree in which these projecting parts have been broken away during the apparently similar cosmical violences to which both fossils have been subject. Besides the post-glenoid ridge (Plates II. & III. *l*) in *Thylacoleo*, there is a narrower boundary wall descending in the inner or mesial end of the articular surface, nearly as low as the posterior one; it renders the surface concave in the transverse direction; and against this "entoglenoid process" (ib. *e*) abuts the apex of a thick obtuse triangular mass of bone, with the base turned toward the descending basisphenoid ridge, but separated from it and from the end of the pterygoid by a groove. This convex portion of bone (Plate III. 6) appears to be developed from the base of the alisphenoid, and to have contributed to the tympanic cavity, like the second "bulla ossea" in *Perameles*[*]; it was broken away on both sides in the first-described skull, but the pneumatic cavity by which it was excavated is partly shown on the left side (Philosophical Transactions, 1859, Plate XIV. 6); its base is perforated by the "foramen ovale."

In the present skull the cranium has been broken across lengthwise, and almost horizontally, exposing the extension of the air-sinuses (Plate IV. fig. 4) from the nose to the occiput, raising the outer table of the cranium nearly 2 inches above the inner one at the middle of the intertemporal ridge, and showing the small cerebral cavity restricted to the lower and hinder half of the cranium. The length of this cavity is 4 inches, its breadth 3 inches, its height 2 inches. Neither falx nor tentorium was ossified. The anterior boundary of the "sella" is indicated by a transverse rising produced into a pair of small retroverted "clinoid" processes, but there is no depression below the level of the cranial surface of the basisphenoid. The rhinencephalic compartment is relatively large.

In all the characters of the cranium shown and described in the original specimen the present fossil corresponds therewith. The posterior palatine vacuity, indicated by the smoothly convex inner border of the roof of the mouth parallel with the hind half of the sectorial tooth (in Plate XIV. fig. 1, *d*, *tom. cit.*), is shown in the present skull (Plate III. *d*) to be the fore part of the wide and advanced "palato-nares;" they are divided, mesially, by the presphenoid rostrum and vomer, and are bounded, laterally, by an extension of the palatal process of the maxillary and of the palatine to the pterygoid. This extension (*ib.* $_{20}$), flat below, convex above, contracts to a diameter of eight lines opposite the middle of the posterior nostril, then increases in breadth, and loses in depth as it passes into the pterygoid wall of the wide and deep pterygo-sphenoid basicranial longitudinal median canal. Each posterior bony nostril is longitudinally ovate, with the great end forward, 2 inches in longitudinal and rather more than 1 inch in transverse diameter; with the plane of the opening inclined from without upward and inward, and, more feebly, from before upward and backward. The bony roof of the mouth is thus much reduced in length; a dimension which is surpassed by its breadth between the great carnassial teeth. Its posterior border is thin, and sharp where it forms the fore part of the palatal nostril, and gradually thickens, becoming smoothly convex at the outer side of that aperture. The bony palate is perforated by a pair of apertures about 1 inch in advance of the hind border, and 1½ inch from the anterior end; that on the left side (Plate III. *a*) is elliptic, about 5 lines by 3 lines in its two diameters; on the right side the bony palate is partly broken away: these answer to the incisive or prepalatal foramina, and are on the line of the suture of the premaxillary with the maxillary palatal processes. The breadth of the palate, which is nearly 4 inches between the hind ends of the carnassials, is reduced to 1 inch 3 lines anterior to the small openings above-mentioned, and rapidly contracts to a breadth of 3 lines between the large sockets of the anterior teeth, which here, descending, convert the fore part of the palate into a deep groove.

---

[*] Cyclopædia of Anatomy and Physiology, vol. iii. Art. *Marsupialia*, fig. 96.

The most welcome and instructive part of the present fossil skull is the fore part, giving evidence of the anterior teeth, and of the formation, position, and aspect of the external nostril. This orifice (Plate IV. fig. 1) is formed by the premaxillaries ($_{22}$) and extremities of the nasals ($_{15}$). A characteristic of most of the facial sutures in *Thylacoleo* is their finely undulated or subdentate structure. This is shown between the maxillary (Plate II. $_{21}$) and malar ($_{26}$), between the maxillary ($_{21}$) and premaxillary ($_{22}$), and between the nasals ($_{15}$) and premaxillaries; though not in the median suture between the nasals themselves. These bones (Plates II. & IV. figs. 1 & 3, $_{15}$) slightly expand at their fore ends, where their free margin is thick and obtuse, and forms the upper third of the external nostril. The premaxillaries form the sides of the opening by a similar margin, which rapidly expands at the lower half, to form or be continued, sloping forward, into the alveoli of the pair of incisor tusks (i_1). The inner or medial border of each alveolar outlet (Plate III. i_1) is continued downward below the level of the contiguous bony palate for about 4 lines, forming the sides of a groove or canal at that part about 3 lines in breadth, which expands as the palate extends backward between these alveoli. At the middle of the lower boundary of the external nostril the premaxillaries rise into a slight prominence; the lateral borders of the nostril are slightly concave vertically (Plate II. $_{22}$); the form of the nostril (Plate IV. fig. 1) is transversely elliptic; its plane almost vertical, with the lower border a little advanced; the anterior margin of the nasals is, through fracture, not quite entire. The vertical diameter of the nostril is 1 inch 2 lines, the transverse diameter 1 inch 10 lines. The vertical extent of the premaxillary is

2 inches 7 lines; the antero-posterior extent of the upper part of the premaxillary, or of the naso-premaxillary, suture (Plate III. between 15 & 22) is 2 inches; the maxillo-premaxillary suture (*ib.* between 21 & 22), as it descends, runs forward, reducing that dimension of the bone at the middle of the nostril (22) to 1 inch, whence it expands to 1 inch 8 lines, where it contributes to the alveolar border of the upper jaw and to the bony palate; the pair of incisive or premaxillary palatal foramina, before described (Plate III. *a*), open upon the suture of the premaxillary with the palatal plate of the maxillary.

Each premaxillary has three alveoli; the outlet of the foremost (Plate III. i_1) is oval, with the larger end forward, 1 inch in long diameter, 7½ lines across the widest part: this socket rises for nearly 2 inches in the substance of the bone, inclining a little backward and outward to its closed end; the long axes of the outlets converge forward. The outlet of the second incisor (ib. i_2) is a full ellipse, 4 lines by 3½ lines in the two diameters; that of the third incisor (ib. i_3) seems to have been of similar size. The breadth of both premaxillaries posteriorly is 2 inches 10 lines; anteriorly, across the first alveoli, 1 inch 8 lines; the length of the premaxillary part of the bony palate is 1 inch 7 lines. The maxillary (Plate II. 21) swells outward as it leaves the premaxillary to form the socket of the great carnassial (p_4), above which it rises to join the malar (26), the lacrymal (13), the frontal (11), and the nasal (15) bones. Anterior to the root of the carnassial it is perforated by the small antorbital foramen. Behind the carnassial socket the bone extends outward and backward for 1¼ inch, forming the lower and fore part of the temporal fossa, and there terminating by a free obtuse convex border (*ib.* 21′), of similar vertical extent, below the malo-maxillary suture. The corresponding part of the posterior border of the maxillary in *Felis* is concave. On the inner side of the hinder end of the carnassial socket is that (Plate III. m_1) for the small tubercular tooth, which was preserved in the first described specimen; the long axis of its outlet forms an open angle with that of the carnassial socket, at the fore part of which the alveolar border of the maxillary is excavated by either a similar socket for a two-rooted tooth, or by two contiguous sockets for two small single-rooted teeth (ib. p_3). I think the first the more likely explanation, in which case the long axis of the outlet of this socket forms an open angle with that of the carnassial one, extending therefrom inward and forward, instead of inward and backward, like the posterior socket. The extent of such axis is 6 lines, the first subcircular orifice being rather less, the next rather more than 3 lines in diameter. The fore part of this socket is near the lower end of the maxillo-premaxillary suture, and the state of the alveolar and contiguous palatal part of the jaw here precludes any clear determination relative to a canine; such a tooth (ib. *c*), of small size, conical and obtuse, had been cemented to this broken part of the alveolar border, in the line of the small posterior incisors.

The posterior part of the maxillary is concave as it rises from the border to form the fore part of the temporal fossa, and then bulges out into that fossa as a smooth convexity, on the inner side of which is the hinder opening of the suborbital canal (Plate IV. fig. 3, *o*). Above this convexity the lower and fore part of the orbit impresses that part of the maxillary which supports the lacrymal, which forming that part of the rim of the orbit and extending backward adds to the depth of the depression. The rim subsides above the lacrymal, and the upper part of the orbit is continued convexly upon the upper part of the skull parallel with the posterior ends of the nasals and contiguous part of the frontal (*ib.* $_{11}$). The superorbital ridge is resumed by the outstanding and down-bending process of the frontal (Plate II. $_{12}$), which, being broken away on both sides of the skull, exposes the large air-sinus with which it was excavated. The rimless upper part of the orbit is 10 lines in extent. The orbit is relatively smaller than in *Felis*, deeper anteriorly, and more significantly different by its wall not being pierced for the lacrymal canal, the entry of which (*ib.* $_{13}$) is situated externally, as shown in the first-described specimen of *Thylacoleo.* The length of the nasal bones (Plate IV. fig. 3, $_{15}$) is 3 inches 6 lines; their least breadth, conjointly, is 1 inch; they slightly expand at both ends, but most so posteriorly, where they are 2 inches across. Their median suture remains; that of the frontals is in great part obliterated, and the conjoined frontals (*ib.* $_{11}$) enter the posterior interspace of the nasals. The fronto-nasal suture is undulatory. The nasal processes of the maxillaries do not extend so far back as the nasals, which terminate angularly, but with the apex largely rounded off.

The upper cranial surface of the frontals (Plate IV. fig. 3, $_{11}$) contracts backward to the intertemporal ridge (ib. *t*); the boundary between frontal and parietal is not shown. At the anterior expanded part of the frontals the external surface forms a pair of low convexities divided by a median longitudinal shallow channel, but deeper and with the convexities better marked than in the first specimen. These convexities give a contour line to the upper part of the skull (Plate II.), resembling that in the Brown Bear, which also the skull resembles in the breadth of the naso-maxillary part. The upper and hinder parts of the cranium correspond with those which were characterized in the former paper.

The dentition of the upper jaw, as indicated by alveoli in the present specimen, includes, on each side, three incisors (Plate III. *i*, $_{1}$, $_{2}$, $_{3}$), followed by three or four other teeth: of these, one is the great carnassial (p_{4}), another, the small transversely-oblong tubercular (m_{1}): the seat of doubt is between the carnassials and incisors. To one of the doubts expression has been already given; whether, viz., the carnassial was preceded by one small two-rooted premolar (p_{3}), or by two smaller and single-rooted teeth. A canine appears to be represented by the tooth with a subcircular, conical, obtusely worn crown, under 3 lines in diameter, supported on a thicker base (ib. *c*). Future specimens may clear up this part of the dentition of *Thylacoleo.* It is certain that the anterior incisor (ib. i_{1}) bore a relation of size to the carnassial similar to that of the canine tusk in *Felis* to the carnassial. Of the two small premaxillary teeth which succeeded the front tusk, neither is preserved,

The size of the laniary canine in *Felis* being here transferred to the first incisor, its function as killer was similarly provided for by its approximation to the moving power, through the extreme shortness of both upper and lower jaws, especially anterior to the chief molar teeth. In *Felis* the small incisors are very little in advance of the canine; this large tooth is almost at the fore part of both upper and lower jaws; and in *Thylacoleo* the relative position of the incisor-tusk to the enormous temporal fossa is such as to give it the advantage of a harder or closer grip during the action of the powerful temporal muscles.

In the former paper so much of the characters of the lower jaw, and its teeth, of *Thylacoleo* were given as could be deduced from the cast of a portion of that bone figured in Plates XI. & XIII. figs. 3, 4, & 5, pp. 317 & 318, of the Philosophical Transactions for 1859.

The carnassial and succeeding tubercular teeth, being in place, served to refer this fossil to the same species as that indicated by the upper jaw (Plate XI. figs. 1 & 2, *tom. cit.*). A socket for a second smaller "tubercular" was evident, behind the one in place. The chief doubt remained in regard to the fore part of the mandibular ramus; the plaster-cast did not admit of any certain conclusion as to the extent to which the original might there have suffered fracture; part of the symphysial surface and the base or socket of a large obliquely produced tooth could be made out, and this "seemed to be the sole tooth in advance of" the carnassial. Accordingly I wrote, "If the ramus be really produced at the upper part of the symphysis further than is indicated in the present cast, it may have contained one or more incisors, and the broken tooth in question may be the lower canine. If, however, this be really the foremost tooth of the jaw, it would appear to be one of a pair of large incisors, according to the marsupial type exhibited by the *Macropodidæ* and *Phalangistidæ*" (*loc. cit.* p. 318).

The perfect condition of the upper jaw of the chief subject of the present paper determined the alternative, and proved the *Thylacoleo* to be the carnivorous modification of the more common and characteristic type of Australian Marsupials, having the incisors of the lower jaw reduced to a pair of large, more or less procumbent and approximate, conical teeth or "tusks."

I have been favoured by Mr. GERARD KREFFT, the able Curator of the Australian Museum, Sydney, New South Wales, with a "photograph" of the outer side, and an outline sketch, natural size, of the inner side, of a portion of the right mandibular ramus of *Thylacoleo carnifex* in that Museum, which presents the same general resemblance, in the kind and degree of mutilation, to the original of the cast described in Part I., which the cranium from the "Condamine River" presents to the one from "Colungoolac." It is fortunately, however, a little more complete; sufficiently so to demonstrate that the large socket (Plate IV. figs. 5 & 6, *i*) is of the foremost tooth of the lower jaw. It also exhibits two small approximate alveoli, or the divisions of an alveolus, for a two-fanged tooth, corresponding in size and in relative position to the carnassial, with the similar socket or sockets noticed in the description of the upper jaw (Plate III. p_3). There are evidently no smaller incisors behind the large one of the lower jaw, nor any other teeth between the large incisive tusk and the small tooth or teeth on the inner side of the fore part of the great lower carnassial. The portion of lower jaw in the Sydney Museum also shows the socket for the minute tubercular tooth (Plate IV. figs. 5 & 6, m_2) behind the posterior double-rooted one (*ib.* m_1). The "foramen mentale," the anterior boundary of the depression for the insertion of the large temporal muscle, and the form of symphysis, closely resemble all these characters as shown by the cast of the mandible first described. Mr. Krefft has dotted the depth to which the socket of the lower incisive tusk descends in the symphysial part of the jaw (*ib.* fig. 6, *i*): it is somewhat greater than that of the upper tusk.

The length of the dental series of the upper jaw, in a straight line, is 4 inches 3 lines; that of the lower jaw is 3 inches 3 lines.

From present data the probable formula of *Thylacoleo* is:—$i\,\frac{3-3}{?}$, $c\,\frac{1-1}{?}$, $p\,\frac{2-2}{2-2}$, $m\,\frac{1-1}{2-2}=24$. Of the incisors of the upper jaw, the first is a large tusk; of the premolars, the first is small, probably two-fanged, the second a very large carnassial. The first molar is small and two-fanged in both jaws, the second is restricted to the lower jaw, is still smaller, and is single-rooted. The chief business of the teeth has been delegated to the tusks and carnassials: development has been concentrated on these at the cost of the rest of the normal or typical dental series. The foremost teeth seized, pierced, lacerated or killed, the carnassials divided the nutritive fibres of the prey.

Thylacoleo exemplifies the simplest and most effective dental machinery for predatory life and carnivorous diet known in the Mammalian class. It is the extreme modification, to this end, of the Diprotodont type of *Marsupialia.*

Besides the full confirmation which the additional fossils, here described, give of the marsupiality of *Thylacoleo*, its closer affinities in that Order are shown to be, not to the existing Carnivorous Marsupials, e. g., *Sarcophilus*, *Dasyurus*, *Thylacinus*, *Didelphys*, but to the Diprotodons, Nototheres, Koalas, Phalangers, and Kangaroos. It may, I think, be said that the skull above described is one of the most singular and interesting mammalian fossils hitherto discovered.

Admeasurements of the Skull.

	in.	lin.
Length	9	8
Length of the facial part anterior to the orbit	3	0
Breadth at the preserved posterior part of the zygoma	7	2
Breadth at the preserved anterior root of the zygoma	6	9
Breadth of the cranium between the temporal fossæ	2	3
Length of the bony palate, from the fore border of the palato-nares	2	11
Breadth of the bony palate at the same part	3	6
From the fore end of premaxillary to the hind border of the palato-nares	4	9
From the hind border of the palato-nares to that of the occipital condyles	5	6
Length of the temporal fossa, including the orbit	7	2
Breadth of the interorbital space across the antero-superorbital ridges	3	10
Breadth of the interorbital space behind the antero-superorbital ridges	3	0
Least breadth of the foramen magnum	0	11

	in.	lin.
Least height of the foramen magnum	0	7
Breadth between the upper ends of the condyles	1	4
Breadth across the broadest part of the condyles	2	5
Breadth across the paroccipitals	4	2
Breadth across the mastoids	5	3
Vertical diameter, or depth of the upper jaw, at and including the fore part of the carnassial tooth	4	0
Vertical diameter, or depth of the mandible, at and including the fore part of the carnassial tooth	3	0

Other admeasurements are noted in the text.

Description of the Plates.

PLATE II.

Side view of the skull, without the mandible, of the *Thylacoleo carnifex*:—nat. size.

PLATE III.

Base view of the skull of the *Thylacoleo carnifex*:—nat. size.

PLATE IV.

Fig. 1. Front view of the skull of the *Thylacoleo carnifex*.

Fig. 2. Back view of the same skull.

Fig. 3. Upper view of the same skull.

Fig. 4. Air-cells of the diploë above the cavity for the brain.

Fig. 5. Outer side of part of the right mandibular ramus, with the carnassial (p_4) and first molar (m_1).

Fig. 6. Inner side of the same portion of mandible: the second molar (m_2) and the incisive tusk (i) are indicated in outline.

All the figures in this Plate are half the natural size.

The letters and figures are explained in the text.

V. *Sixth Memoir on Radiation and Absorption.—Influence of Colour and Mechanical Condition on Radiant Heat. By Professor* J. Tyndall, *LL.D., F.R.S., Member of the Academies and Societies of Holland, Geneva, Göttingen, Zürich, Halle, Marburg, Breslau, Upsala, Cherbourg, la Société Philomathique of Paris, Cam. Phil. Soc. &c.; Professor of Natural Philosophy in the Royal Institution and the Royal School of Mines.*

Received December 21, 1865,—Read January 18, 1866.

Franklin placed cloths of various colours upon snow and allowed the sun to shine upon them. They absorbed the solar rays in different degrees, became differently heated, and sank therefore to different depths in the snow beneath them. His conclusion was that dark colours were the best absorbers, and light colours the worst, and to this hour we appear to have been content to accept Franklin's generalization without qualification. In my last memoir I briefly pointed out its probable defects. Did the emission from luminous sources consist exclusively of visible rays, we might fairly infer from the colour of a substance its capacity to absorb the heat of such sources. But the emission from luminous sources is by no means all visible. In terrestrial sources by far the greater part, and in the case of the sun a very great part of the emission, consists of invisible rays, regarding which colour teaches us nothing.

It remained therefore to examine whether the results of Franklin were the expression of a law of nature. Two cards were taken of the same size and texture; over one of them was shaken the white powder of alum, and over the other the dark powder of iodine. Placed before a glowing fire and permitted to assume the maximum temperature due to their position, it was found that the card bearing the alum became extremely hot, while that bearing the iodine remained cool. No thermometer was necessary to demonstrate this difference. Placing, for example, the back of the iodine card against the forehead or cheek, no inconvenience was experienced; while the back of the alum card similarly placed proved intolerably hot.

This result was corroborated by the following experiments:—One bulb of a differential thermometer was covered with iodine, and the other with alum powder. A red-hot spatula being placed midway between both, the liquid column associated with the alum-covered bulb was immediately forced down, and maintained in an inferior position. Again, two delicate mercurial thermometers had their bulbs coated, the one with iodine, the other with alum. On exposing them at the same distance to the radiation from a gas-flame, the mercury of the alum-covered thermometer rose nearly twice as high as that of its neighbour. Two sheets of tin were coated, the one with alum, and the other with iodine powder. The sheets were placed parallel to each other and about 10 inches asunder; at the back of each was soldered a little bar of bismuth, which with the tin plate to which it was attached constituted a thermo-electric couple. The two plates were connected together by a wire, and the free ends of the bismuth bars were connected with a galvanometer. Placing a red-hot ball midway between both, the calorific rays fell with the same intensity on the two sheets of tin, but the galvanometer immediately declared that the sheet which bore the alum was the most highly heated.

In some of the foregoing cases the iodine was simply shaken through a muslin sieve; in other cases it was mixed with bisulphide of carbon and applied with a camel's-hair brush. When dried afterwards it was almost as black as soot, but as an absorber of radiant heat it was no match for the perfectly white powder of alum.

The difficulty of warming iodine by radiant heat is evidently due to the diathermic property which it manifests so strikingly when dissolved in bisulphide of carbon. The heat enters the powder, is reflected at the limiting surfaces of the particles, but it does not lodge itself among the atoms of the iodine. When shaken in sufficient quantity on a plate of rock-salt and placed in the path of a calorific beam, iodine cuts the latter off. But its opacity is mainly that of a white powder to light; it is impervious, not through absorption, but through internal reflexion. Ordinary roll sulphur, even in thin cakes, allows no radiant heat to pass through it, but its opacity is also due to repeated internal reflexion. The temperature of ignition of sulphur is about 244° C.; but on placing a small piece of the substance at the focus of the electric lamp where the temperature was sufficient to heat platinum foil in a moment to whiteness, it required exposure for a considerable time to fuse and ignite the sulphur. Though impervious to the heat, it was not adiathermic. The milk of sulphur was also ignited with some difficulty. Sugar is a much less inflammable substance than sulphur, but it is a far better absorber; exposed at the focus, it is speedily fused and burnt up. The heat moreover which is competent to inflame sugar is scarcely competent to warm table salt.

A fragment of almost black amorphous phosphorus was exposed at the dark focus of the electric lamp, but refused to be ignited. A still more remarkable result was obtained with ordinary phosphorus. A small fragment of this exceedingly inflammable substance could be exposed for twenty seconds without ignition at a focus where platinum was almost instantaneously raised to a white heat. Placing a morsel of phosphorus on a plate of rock-salt and holding it before a glowing fire, it bears, as proved by my assistant, Mr. Barrett, an intense radiation without ignition, but laid upon a plate of glass and similarly exposed, the phosphorus soon fuses and ignites; its ignition, however, is not entirely due to radiant heat, but mainly to the heat imparted to it by the glass[*].

The fusing-point of phosphorus is about 44° C., that of sugar is 160°; still at the focus of the electric lamp the sugar fuses before the phosphorus. All this is due to the diathermancy of the phosphorus. A thin disk of the substance placed between two plates of rock-salt permits of a copious transmission. This substance therefore takes its place with other elementary bodies as regards deportment towards radiant heat.

---

[*] I believe this deportment of phosphorus towards radiant heat is not unknown to chemists.

The more diathermic a body is, the less it is warmed by radiant heat. No perfectly transparent body could be warmed by purely luminous heat. The surface of a vessel covered with a thick fur of hoar frost was exposed to the beam of the electric lamp condensed by a powerful mirror, the beam having been previously sent through a cell containing water; the sifted beam was powerless to remove the frost, though it was competent to set wood on fire. We may largely apply this result. It is not, for example, the luminous rays, but the dark rays of the sun which sweep the snows of winter from the slopes of the Alps. Every glacier stream that rushes through the Alpine valleys is almost wholly the product of invisible radiation. It is also the invisible solar rays which lift the glaciers from the sea-level to the summits of the mountains; for the luminous rays penetrate the tropical ocean to great depths, while the non-luminous ones are absorbed close to the surface, and become the main agents in evaporation.

It is often stated, without limitation, that ether might be exposed at the focus of a concave mirror without being sensibly heated; but this can only be true of a sifted beam. At the focus of the electric lamp, not only ether, but alcohol and water are speedily caused to boil, while bisulphide of carbon, whose boiling-point is only 48° C., cannot be raised to ebullition. In fact exposure for a period sufficient to boil alcohol or water is scarcely sufficient to render bisulphide of carbon sensibly warm.

If any one point came out with more clearness than any other in my experiments on gases, liquids, and vapours, it was the paramount influence which chemical constitution exerted upon the phenomena of radiation and absorption. And seeing how little the character of the radiation was affected by the change of a body from the state of vapour to the state of liquid, I held it to be exceedingly probable that even in the solid state chemical constitution would exert its power. But opposed to this conclusion we had the experiments of MELLONI on chalk and lampblack, and the far more extensive ones of MASSON and COURTÉEPÉE on powders, which seemed clearly to show that in a state of extremely fine division, as in chemical precipitates, the radiant and absorbent powers of all bodies are the same. From these experiments it was inferred that the influence of physical condition was so predominant as to cause that of chemical constitution to disappear*.

A serious oversight, however, seems to have connected itself with all the experiments of these distinguished men. MELLONI mixed his lampblack and powdered chalk with gum or glue, and applied them by means of a camel's-hair brush on the surfaces of his radiating cube. MASSON and COURTÉEPÉE did the same. MELLONI, it is true, thus compared a black surface with a white one; but the surfaces were seen to be white and black *through* the transparent gum, which in both cases was the real radiator. The same remark applies to MASSON and COURTÉEPÉE. Every particle of the precipitates they employed was a varnished particle; and the constancy they observed was, I imagine, due to the fact that the main radiant in all their experiments was the substance employed to make their powders cling to the surfaces of their cubes.

---

* MASSON and COURTÉEPÉE, Comptes Rendus, vol. xxv. p. 938; JAMIN, Cours de Physique, vol. ii. p. 289.

Gum or glue is a powerful radiator; in fact equal to lampblack, and it is a correspondingly powerful absorber. The particles surrounded by it had therefore but small chance of radiating through it. I sought to remedy this by the employment of a diathermic cement. Sulphur is highly diathermic; it dissolves freely in bisulphide of carbon, and at the suggestion of a chemical friend I employed it to fix the powders. The cube was laid upon its side, the surface to be coated being horizontal, and the bisulphide, containing the sulphur in solution, was poured over the surface. Before the liquid film had time to evaporate, the powder was shaken upon it through a muslin sieve. The bisulphide passed rapidly away in vapour, leaving the powder behind imbedded in the sulphur cement. Each powder, moreover, was laid on sufficiently thick to prevent the sulphur from surrounding its particles. This, though not perhaps a perfect way of determining the radiation of powders, was at all events an improvement on former methods, and yielded different results.

Ten or twelve cubes of tin were employed in the investigation. One side of each of them was coated with milk of sulphur, and this substance running through the entire series of cubes, enabled me to connect the results of all of them together. The cubes were heated with boiling water, and placed in succession at the same fixed distance in front of the thermo-electric pile, which as usual was well defended from air-currents and other extraneous sources of disturbance. Before giving the complete table of results I will adduce a few of them, which show in a conclusive manner that in solid bodies radiation is molecular rather than mechanical.

The biniodide of mercury and the red oxide of lead resemble each other physically, both of them being of a brilliant red. Chemically, however, they are very different. Examined in the way indicated, their relative powers as radiators were found to be as follows:—

Name.	Chemical formula.	Radiation.
Biniodide of Mercury . . .	$(Hg I_2)$	39·7
Red oxide of Lead	$(2Pb O, Pb O_2)$	74·1

Mixed with gum and applied with a camel's-hair brush to the surfaces of the cube, the radiation from the following two substances fell out thus:—

Name.	Radiation.
Binoxide of Mercury	80·0
Red oxide of Lead	80·0

Here the influence of the gum entirely masks the difference due to molecular constitution.

The effect of atomic complexity upon the radiation is well illustrated by the deportment of these two substances. It is further illustrated by the deportment of two different iodides of mercury:—

	Radiation.
Biniodide of Mercury ($Hg\,I_2$)	39·7
Iodide of Mercury ($Hg_2\,I_2$)	46·6

Here the addition of a second atom of mercury to the molecule of the biniodide raises the radiation seven per cent. The experiment furnishes a kind of physical justification of the practice of chemists in regarding the molecule of yellow iodide of mercury to be $Hg_2\,I_2$, and not $Hg\,I$.

The peroxide and protoxide of iron gave the following results:—

	Radiation.
Peroxide of Iron	78·4
Protoxide of Iron	81·3

I did not expect this, the protoxide being a less complex molecule than the peroxide. On examination, however, the protoxide was found to be in part the magnetic oxide. The formulæ of the two substances are $Fe_2\,O_3$ and $Fe\,O, Fe_2\,O_3$, and the anomaly therefore disappears.

Amorphous phosphorus and sulphide of iron gave the following results:—

	Radiation.
Amorphous Phosphorus	63·6
Sulphide of Iron	81·7

Sugar and salt were reduced in a mortar to the state of exceedingly fine powders. In point of cohesion and physical aspect these substances closely resemble each other; their radiative powers, however, are as follows:—

	Radiation.
Salt	35·3
Sugar	70·0*

In his last interesting paper on emission at a red heat†, M. Desains mentions oxide of zinc as a body which at 100° C. has the same emissive power as lampblack. This is nearly true for the hydrated oxide; with the calcined oxide the following is the relation:—

	Radiation.
Lampblack	84·0
Hydrated oxide of Zinc	80·4
Calcined	53·2

---

[*] I have of course no intention of adducing experiments on sugar and salt, or on powdered rock-salt and alum, as opposed to the results of Masson and Courtépée. They would regard their results as unaffected by such experiments. It is the deportment of the *chemical precipitates* employed, and not that of bodies reduced to powder by mechanical means, that invalidate their conclusions.

[†] Comptes Rendus, July 3rd, 1859; Phil. Mag. Aug. 1865.

Two red powders have been already compared together, I will now compare two black ones. With black platinum and black oxide of iron the following results were obtained:—

	Radiation.
Black Platinum (electrolytic)	59·0
Black oxide of Iron	81·3

The black platinum here employed was obtained by electrolysis, a sheet of platinum foil being coated with the substance.

Let us now compare two white powders. Chloride of silver and carbonate of zinc gave the following results:—

	Radiation.
Chloride of Silver	32·5
Carbonate of Zinc	77·7

As in all the other cases the influence of chemical constitution makes its appearance here.

When held upon its cube by the sulphur cement, the chloride of silver soon darkens in the diffuse light of the laboratory. It first becomes lavender, and passes through various stages of brown to black. During these changes, which may be associated with a chemical reaction between the chloride of silver and the sulphur in which it is imbedded, the radiation steadily augments. Beginning in one instance with a radiation of 25, the chloride ended with a radiation of 60.

We have thus far compared two red surfaces, two black surfaces, and two white surfaces together. The comparison of a black and white surface gave the following result:—

	Radiation.
Black Platinum	59·0
White hydrated oxide of Zinc	80·4

Here the radiation from the white body far transcends that from the black one.

Again, comparing black and white, we have the following result:—

	Radiation.
Oxide of Cobalt	76·5
Carbonate of Zinc	77·7

Here the black radiation is sensibly equal to the white one.

Finally, comparing black and white, we have the following result:—

	Radiation.
Lampblack	84·0
Chloride of Lead	55·4

Here the radiation from the black body far transcends that from the white one.

We have thus compared red powders with red, black with black, white with white, and black with white; and the conclusion to be drawn from the experiments is, I think, that chemical constitution, so far from being of vanishing value, is the really potent influence in the experiments.

Were the radiative power of these substances determined by the state of division, I think it must make itself sensible even in a case where the division is effected by the pestle and mortar; but I do not find this to be the case. A plate of glass was fixed against the polished surface of a LESLIE'S cube, and on the plate the powder of glass, rendered as fine as the pestle and mortar could make it, was strewn. It was caused to adhere without cement of any kind. The cube was filled with boiling water and presented to the thermo-electric pile until a permanent deflection was obtained. Permitting the cube to remain in its position, the powder was removed with a camel's-hair brush. An inconsiderable augmentation of the radiation was the result, the increase being such as might be expected to follow from the slight difference of temperature between the surface of the glass plate and the powder which had been strewn upon it. Similar experiments were made with a plate of rock-salt, on which finely divided powder of rock-salt was shaken. The result was precisely similar to that obtained with the glass powder.

One side of a LESLIE'S cube was covered by a sheet of bright platinum foil, and a second face by a similar sheet on which black platinum had been deposited by electrolysis. As radiators these two sheets of foil behaved in the following manner:—

	Radiation.
Bright Platinum foil	6·0
Platinized Platinum	45·2

Here the radiation of the black platinum is nearly eight times that of the bright substance.

Having thus shown, I trust conclusively, that the influence of chemical constitution makes itself felt in all states of aggregation, for the sake of reference, I will here tabulate the results obtained with a considerable number of powders when subjected to the same conditions of experiment.

TABLE I.—Radiation from Powders imbedded in Sulphur Cement.

Substance.	Radiation.
Rock-salt	35·3
Biniodide of Mercury . . .	39·7
Milk of Sulphur	40·6
Common Salt	41·3
Yellow iodide of Mercury . .	46·6
Sulphide of Mercury	46·6
Iodide of Lead	47·3
Chloride of Lead	55·4
Chloride of Cadmium . . .	56·5
Chloride of Barium	58·2
Chloride of Silver (dark) . .	58·6

TABLE I. (continued).

Substance.	Radiation.
Fluor-spar	68·4
Tersulphide of Antimony	69·4
Carbonate of Lime	70·2
Oxysulphide of Antimony	70·5
Sulphide of Calcium	71·0
Sulphide of Molybdenum	71·3
Sulphate of Baryta	71·6
Chromate of Lead	74·1
Red oxide of Lead	74·2
Sulphide of Cadmium	76·3
Subchloride of Copper	76·5
Oxide of Cobalt	76·7
Sulphate of Lime	77·7
Carbonate of Zinc	77·7
Red oxide of Iron	78·4
Sulphide of Copper	79·0
Hydrated oxide of Zinc	80·4
Black oxide of Iron	81·3
Sulphate of Iron	81·7
Iodide of Copper	82·0
Lampblack	84·0

I subsequently endeavoured to get rid of the sulphur cement and to make the powders adhere by wetting them with pure bisulphide of carbon, applying them to the cubes while wet. Some of the powders clung, others did not. My ingenious friend Mr. DUPPA suggested to me that the powders might be held on by electrifying the cubes. I tried this plan, and found it simple and practicable. It was, however, aided by a circumstance which we did not anticipate. The cube being placed upon an insulating stand, the powder was shaken over it, and electrified by a few turns of a machine. It was found that the cube might then be discharged and set upright, the powders clinging to it in this position. The results obtained with this arrangement are recorded in the following Table:—

TABLE II.—Radiation from Powders held by Electricity.

Substance.	Radiation.
Rock-salt	24·5
Chloride of Silver (white)	25·0
Milk of Sulphur	25·8
Biniodide of Mercury	26·0

TABLE II. (continued).

Substance.	Radiation.
Iodide of Lead	36·0
Sulphide of Mercury	30·6
Spongy Platinum	31·5
Washed Sulphur (flowers)	32·3
Sulphide of Zinc	36·1
Amorphous Phosphorus	38·0
Chloride of Lead	39·0
Chloride of Cadmium	40·0
Fluor-spar	48·6
Sulphide of Calcium	49·1
Sulphate of Baryta	51·3
Sugar	52·1
Red oxide of Lead	56·5
Sulphide of Cadmium	56·9
Sulphate of Lime	59·3
Chloride of Silver (black)	60·0
Carbonate of Zinc	62·0
Oxide of Cobalt	62·5
Iodide of Copper	63·0
Red oxide of Iron	63·8
Sulphide of Iron	65·5
Black oxide of Iron	65·8

The agreement as regards relative radiative power between this and the former Table is as good as could under the circumstances be expected. The experiments have been several times repeated, and the Table contains the means of results which were never widely different from each other.

The *quantity* of radiant heat emitted by bodies in all states of aggregation having been thus conclusively shown to depend mainly upon its molecular character, the question as to the *quality* of the heat emitted next arises. In examining this point, I contented myself with testing the heat by its transmission through rock-salt. The choice of this substance involved the solution of the still disputed question whether rock-salt is equally pervious to all kinds of rays*. For if it absorbed the radiation from two different bodies in different degrees, it would not only show a difference of quality in the radiations, but also demonstrate its own incapacity to transmit equally rays of all descriptions.

---

* The last publication on this subject is from the pen of that extremely able experimenter, Professor KNOBLAUCH. After discussing the results of DE LA PROVOSTAYE and DESAINS, and of Mr. BALFOUR STEWART, he arrives at a different conclusion, namely, that pure rock-salt is equally pervious to all kinds of heat.—POGG. Ann. 1863, vol. cxx. p. 177.

The plate of rock-salt chosen for this purpose was a very perfect one. I have never seen one more pellucid. The thickness was 0·8 of an inch, and its size, compared with the aperture in front of which it was placed, was such as to prevent any part of the rays reflected from its lateral boundaries from mingling with the direct radiation. M. Knoblauch has clearly shown how the absence of caution in this particular may lead to error. The mode of experiment was that usually followed: the source was first permitted to radiate against the pile, and the deflection produced by the total radiation noted. The plate of rock-salt being then interposed, the deflection sank, and from its new value the transmission through the rock-salt was calculated and expressed in hundredths of the total radiation.

Table III.—Transmission through Rock-salt from the following substances raised to a temperature of 100° C.

Substance.	Transmission.	Radiation.
Rock-salt	67·2	35·3
Biniodide of Mercury	76·3*	39·7
Milk of Sulphur	76·9*	40·6
Common Salt	70·8	41·3
Yellow iodide of Mercury	79·0*	46·6
Sulphide of Mercury	73·1	46·6
Iodide of Lead	73·8	47·3
Chloride of Lead	73·1	55·4
Chloride of Cadmium	73·2	56·5
Chloride of Barium	70·7*	58·2
Chloride of Silver (dark)	74·2	58·6
Fluor-spar	70·5*	68·4
Tersulphide of Antimony	77·1	69·4
Carbonate of Lime	77·6	70·2
Oxysulphide of Antimony	77·6	70·5
Sulphide of Molybdenum	78·4	71·3
Sulphate of Baryta	71·3	78·4
Chromate of Lead	71·6	79·2
Red oxide of Lead	74·1	79·2
Subchloride of Copper	76·3	78·6
Oxide of Cobalt	76·5	79·7
Red oxide of Iron	78·4	81·0
Sulphide of Copper	79·0	82·3
Black oxide of Iron	81·3	82·7
Sulphide of Iron	81·7	83·3
Lampblack	84·0	83·3

Here we have a transmission varying from 67 per cent. in the case of powdered rock-salt to 84 per cent. in the case of lampblack. The powders employed were fixed by the sulphur cement. The same powders held by electricity, and permitted to radiate through the rock-salt, gave the following transmissions:—

TABLE IV.

Substance.	Transmission.
Rock-salt	62·8
Chloride of Silver (white)	69·7
Fluor-spar	70·7
Sulphide of Mercury	71·0
Sulphide of Calcium	72·5
Milk of Sulphur	72·8
Sulphide of Cadmium	73·3
Biniodide of Mercury	73·7
Washed Sulphur	74·0
Iodide of Lead	74·1
Sulphate of Lime	74·2
Sulphide of Zinc	74·4
Carbonate of Zinc	74·8
Sulphate of Baryta	75·0
Common Sugar	75·4
Sulphide of Copper	76·5
Iodide of Copper	76·5
Red oxide of Iron	76·8
Chloride of Silver (black)	77·3
Amorphous Phosphorus	78·0
Oxide of Cobalt	78·2
Sulphide of Iron	78·5
Black oxide of Iron	79·7
Black Platinum	89·0

The transmissions here are lower than when the sulphur cement was employed. I do not, however, think that the differences are due to the employment of the cement, but to a slight source of disturbance, which was removed in the later experiments.

For the heat emitted by black platinum rock-salt manifests its maximum power of transmission, which would lead us to ascribe a maximum dissonance between the vibrating periods of rock-salt and of black platinum. It will also be remarked that, as a general rule, the powerful radiator has its heat more copiously transmitted by the rock-salt than the feeble radiator. To render this clear, I have in Table III. appended to the transmission the corresponding total radiation. The only striking exceptions to this rule exhibited in Table III. are marked with asterisks. This result, I think, is what might fairly be expected; for the character which enables a molecule of one substance to radiate a greater quantity of heat than another, may also be expected to influence its rate of oscillation. Hence, as a general rule, a greater dissonance will exist between the vibrating periods of good radiators and bad radiators, than between the periods of the members of either class. But the greater the dissonance the less will be the absorption; hence, as regards transmission through rock-salt, we have reason to expect that powerful radiators will find a more open door to their emission than feeble ones. This is, as I have said, in general the case. But the rule is not without its exceptions, and the most striking of these is the case of black platinum, which, though but a moderate radiator, sends a greater proportion of heat through rock-salt than any other known substance.

In his latest investigation KNOBLAUCH examined at great length the diathermancy of rock-salt. With his usual acuteness he points out several possible sources of error, and with his customary skill he neutralizes these sources. His conclusion is the same as that of MELLONI, namely, that rock-salt transmits in the same proportion all sorts of rays. On the opposite side we find the experiments of MM. DE LA PROVOSTAYE and DESAINS, and those of Mr. BALFOUR STEWART*, both of which are discussed by KNOBLAUCH. He differs from those experimenters, while my results bear them out. Considering the slow augmentation of transmission which the foregoing Tables reveal, and the considerable number of bodies whose heat is transmitted in almost the same proportion by rock-salt, it is easy to see that, where the number of radiants is restricted, such a uniformity of transmission might manifest itself as would lead to the conclusion of MELLONI and KNOBLAUCH. It was only by the selection and extension of the substances chosen as radiators that the differences were brought out with the distinctness recorded in the foregoing Tables.

The differences in point of quality and the absence of perfect diathermancy in rock-salt appear more striking when instead of the transmissions we take the absorptions. In the case of the radiation from powdered rock-salt, for example, 37·2 per cent. of the whole radiation is intercepted by the rock-salt plate. According to MELLONI, between 7 and 8 per cent. of this is lost by reflexion at the two surfaces of the salt. This would leave in round numbers a true absorption of 30 per cent. by the plate of rock-salt. In the case of black platinum, the absorption similarly deduced amounts to only 4 per cent. of the total radiation. Instead, therefore, of the radiation from those two sources being absorbed in the same proportion, the ratio in the one case is more than seven times that in the other. For the sake of illustration here follow a few of the absorptions determined in this way:—

---

* I think the important experiment first executed by Mr. BALFOUR STEWART, of rock-salt radiating through rock-salt, is by itself sufficient to demonstrate in the most unequivocal manner that this substance is not equally pervious to all kinds of rays.

Table V.

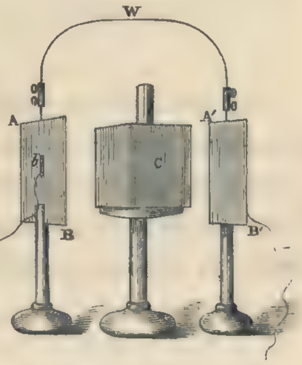
Radiation through Rock-salt.

Source.	Absorption.
Black Platinum	3·7
Black oxide of Iron	13·0
Red oxide of Iron	15·9
Sugar	17·3
Chloride of Silver	22·6
Rock-salt	29·9

These differences of absorption are so great as to enable every experimenter to satisfy himself with the utmost ease as to the unequal permeability of rock-salt, and this facility of demonstration will, I trust, contribute to make inquirers unanimous on this important point.

Theory alone would lead us to the conclusion that the absorptive power of the substances mentioned in Table I. is proportional to their radiative power; nevertheless a few actual experiments on absorption will serve as a check upon those recorded in the Table. These were conducted in the following manner:—

A B is a sheet of common block tin, 5 inches high by 4 in width, fixed upon a suitable stand. At the back of A B is soldered one end of the small bar of bismuth *b*, the remainder of the bar, to its free end, being kept out of contact with the plate by a bit of cardboard. To the free end of *b* is soldered a wire which can be connected with a galvanometer. A′ B′ is a second plate of metal in every respect similar to A B. From one plate to the other stretches the wire W. C is a cube containing boiling water, placed midway between the two plates of metal.



The plates were in the first instance coated uniformly with lampblack, and the two surfaces of the cube which radiated against the plates were similarly coated. The rays from C being emitted equally right and left, and absorbed equally by the two coated plates A B and A′ B′, warmed these plates to the same degree; it is manifest from the arrangement that, if the thermo-electric junctions were equally sensitive, the current generated at the one ought exactly to neutralize the current from the other junction. This was found to be very nearly the case. It is difficult to make both junctions of absolutely the same sensitiveness; but the moving of the feebler plate a hair's breadth nearer to the cube C enabled it to neutralize exactly the radiation from its opposite neighbour. My object now was to compare the lampblack coating of the plate A B with a series of other coatings, which were placed in succession on the other plate. These latter coatings were the powders already employed, and they were held upon A′ B′ by their own adhesion.

When A B was coated with lampblack and A′ B′ with rock-salt powder, the equilibrium observed when both the plates were coated with lampblack did not exist. The lampblack, by its greater absorption, heated its bismuth junction most, and a permanent deflection of 59° in favour of the lampblack was obtained. Other powders were then substituted for the rock-salt, and the difference between them and the lampblack was determined in the same way. When, for example, sulphide of iron was employed, there was a deflection of 30° in favour of lampblack. The results obtained with six different powders thus compared with lampblack are given in the following Table:—

TABLE VI.

Excess of lampblack above	Rock-salt	59°	=	112 units.
,, ,,	Fluor-spar . . .	46	=	68 ,,
,, ,,	Red Lead	40	=	45 ,,
,, ,,	Oxide of Cobalt . .	37	=	42 ,,
,, ,,	Sulphide of Iron .	30	=	30 ,,

The order of absorption here shown coincides with the order of radiation of the same substances shown in Table III. But we can go further than the mere order of absorption. Removing the opposing plate, and allowing the standard lampblack to exert its full action upon the galvanometer, the deflection observed was

65°=163 units.

The numbers in Table VI. show us the excess of the lampblack over the substances there employed; its excess in the case of rock-salt, a bad absorber, being 112, its excess in the case of sulphide of iron being only 30. Deducting, therefore, the numbers given in Table VI. from 163, the total absorption of lampblack, we obtain a series of numbers which expresses the absorptions of the other substances. This series stands as follows:—

TABLE VII.

Substance.	Relative absorptions.		Radiation.
Rock-salt	51	25·5	25
Fluor-spar . . .	95	47·5	49
Red Lead . . .	118	59·0	57
Oxide of Cobalt. .	121	60·5	62
Sulphide of Iron .	133	66·5	66

The first column of figures expresses the relative absorptions; for the sake of comparison with the corresponding radiations, I have placed the halves of these numbers in the second column of figures, and in the third column the radiations obtained from Table II. The approximation of the figures in the second and third columns is seen to be extremely close.

Throughout this investigation I have been efficiently assisted by Mr. W. F. BARRETT, whose rapid progress in scientific knowledge and experimental skill during the three years that he has assisted me has given me great satisfaction.

VI. *Addition to the Memoir on* Tschirnhausen's *Transformation.*

By Arthur Cayley, *F.R.S.*

Received October 24,—Read December 7, 1866.

In the memoir "On Tschirnhausen's Transformation," Philosophical Transactions, vol. clii. (1862) pp. 561–568, I considered the case of a quartic equation: viz. it was shown that the equation

$$(a, b, c, d, e \between x, 1)^4=0$$

is, by the substitution

$$y=(ax+b)\mathrm{B}+(ax^2+4bx+3c)\mathrm{C}+(ax^3+4bx^2+6cx+3d)\mathrm{D},$$

transformed into

$$(1, 0, \mathfrak{C}, \mathfrak{D}, \mathfrak{E} \between y, 1)^4=0,$$

where $(\mathfrak{C}, \mathfrak{D}, \mathfrak{E})$ have certain given values. It was further remarked that $(\mathfrak{C}, \mathfrak{D}, \mathfrak{E})$ were expressible in terms of U', H', Φ', invariants of the two forms $(a, b, c, d, e \between \mathrm{X}, \mathrm{Y})^4$, $(\mathrm{B}, \mathrm{C}, \mathrm{D} \between \mathrm{Y}, -\mathrm{X})^2$, of I, J, the invariants of the first, and of Θ', $=\mathrm{BD}-\mathrm{C}^2$, the invariant of the second of these two forms,—viz. that we have

$$\mathfrak{C}=6\mathrm{H}'-2\mathrm{I}\Theta',$$

$$\mathfrak{D}=4\Phi',$$

$$\mathfrak{E}=\mathrm{IU}'^3-3\mathrm{H}'^2+\mathrm{I}^2\Theta'^2+12\mathrm{J}'\Theta'\mathrm{U}'+2\mathrm{I}'\Theta'\mathrm{H}'.$$

And by means of these I obtained an expression for the quadrinvariant of the form

$$(1, 0, \mathfrak{C}, \mathfrak{D}, \mathfrak{E} \between y, 1)^4;$$

viz. this was found to be

$$=\mathrm{IU}'^2+\tfrac{4}{3}\mathrm{I}^2\Theta'^2+12\mathrm{J}\Theta'\mathrm{U}'.$$

But I did not obtain an expression for the cubinvariant of the same function: such expression, it was remarked, would contain the square of the invariant Φ'; it was probable that there existed an identical equation,

$$\mathrm{JU}'^3-\mathrm{IU}'^2\mathrm{H}'+4\mathrm{H}'^3+\mathrm{M}\Theta'=-\Phi'^2,$$

which would serve to express Φ'^2 in terms of the other invariants; but, assuming that such an equation existed, the form of the factor M remained to be ascertained; and until this was done, the expression for the cubinvariant could not be obtained in its most simple form. I have recently verified the existence of the identical equation just referred to, and have obtained the expression for the factor M; and with the assistance of this identical equation I have obtained the expression for the cubinvariant of the form

$$(1, 0, \mathfrak{C}, \mathfrak{D}, \mathfrak{E} \between y, 1)^4.$$

The expression for the quadrinvariant was, as already mentioned, given in the former memoir: I find that the two invariants are in fact the invariants of a certain linear function of U, H; viz. the linear function is $=\mathrm{U'U}+\frac{2}{3}\Theta'\mathrm{H}$; so that, denoting by I^*, J^*, the quadrinvariant and the cubinvariant respectively of the form

$$(1, 0, \mathfrak{C}, \mathfrak{D}, \mathfrak{E} \between y, 1)^4,$$

we have

$$\mathrm{I}^*=\tilde{\mathrm{I}}(\mathrm{U'U}+4\Theta'\mathrm{H}),$$

$$\mathrm{J}^*=\tilde{\mathrm{J}}(\mathrm{U'U}+4\Theta'\mathrm{H}),$$

where $\tilde{\mathrm{I}}$, $\tilde{\mathrm{J}}$ signify the functional operations of forming the two invariants respectively. The function $(1, 0, \mathfrak{C}, \mathfrak{D}, \mathfrak{E} \between y, 1)^4$, obtained by the application of TSCHIRNHAUSEN'S transformation to the equation

$$(a, b, c, d, e \between x, 1)^4=0,$$

has thus the *same invariants* with the function

$$\mathrm{U'U}+4\Theta'\mathrm{H}=\mathrm{U'}(a, b, c, d, e \between x, 1)^4+4\Theta'(ac-b^2, ad-bc, ae+2bd-3c^2, be-cd, ce-d^2 \between x, 1)^4,$$

and it is consequently a linear transformation of the last-mentioned function; so that the application of TSCHIRNHAUSEN'S transformation to the equation $\mathrm{U}=0$ gives an equation linearly transformable into, and thus virtually equivalent to, the equation

$$\mathrm{U'U}+4\Theta'\mathrm{H}=0,$$

which is an equation involving the single parameter $\frac{4\Theta'}{\mathrm{U'}}$: this appears to me a result of considerable interest. It is to be remarked that TSCHIRNHAUSEN'S transformation, wherein y is put equal to a rational and integral function of the order $n-1$ (if n be the order of the equation in x), is not really less general than the transformation wherein y is put equal to any rational function $\frac{\mathrm{V}}{\mathrm{W}}$ whatever of x; such rational function may, in fact, by means of the given equation in x, be reduced to a rational and integral function of the order $n-1$; hence in the present case, taking V, W to be respectively of the order $n-1$, $=3$, it follows that the equation in y obtained by the elimination of x from the equations

$$(a, b, c, d, e \between x, 1)^4=0,$$

$$y=\frac{(\alpha, \beta, \gamma, \delta \between x, 1)^3}{(\alpha', \beta', \gamma', \delta' \between x, 1)^3}$$

is a mere linear transformation of the equation $\mathrm{AU}+\mathrm{BH}=0$, where A, B are functions (not as yet calculated) of $(a, b, c, d, e, \alpha, \beta, \gamma, \delta, \alpha', \beta', \gamma', \delta')$.

Article Nos. 1, 2, 3.—*Investigation of the identical equation* $\mathrm{JU'^3}-\mathrm{IU'^2H'}+4\mathrm{H'^3}+\mathrm{M}\Theta'=-\Phi'^2$.

1. It is only necessary to show that we have such an equation, M being an invariant,

in the particular case $a=e=1$, $b=d=0$, $c=\theta$, that is for the quartic function $(1, 0, \theta, 0, 1 \between x, 1)^4$; for, this being so, the equation will be true in general. Writing the equation in the form

$$-M\Theta'=U'^2(JU'-IH')+4H'^3+\Phi'^2,$$

and observing that we have

$$\begin{aligned}
U'&=(B^2+D^2)+2\theta BD+4\theta C^2,\\
H'&=\theta(B^2+D^2)+(1+\theta^2)BD-4\theta^2C^2,\\
\Theta'&=BD-C^2,\\
\Phi'&=(1-9\theta^2)C(B^2-D^2),\\
I&=1+3\theta^2,\\
J&=\theta-\theta^3,
\end{aligned}$$

and thence

$$JU'-IH'=-4\theta^3(B^2+D^2)+(-1-2\theta^2-5\theta^4)BD+(8\theta^2+8\theta^4)C^2,$$

the equation becomes

$$\begin{aligned}
-(BD-C^2)M=&\\
&\{-4\theta^3(B^2+D^2)+(-1-2\theta^2-5\theta^4)BD+(8\theta^2+8\theta^4)C^2\}\\
&\qquad\qquad\times\{B^2+D^2+2\theta BD+4\theta C^2\}^2\\
&+4\{\theta(B^2+D^2)+(1+\theta^2)BD-4\theta^2C^2\}^3\\
&+(1-9\theta^2)^2\,C^2\{(B^2+D^2)^2-4B^2D^2\}.
\end{aligned}$$

2. It is found by developing that the right-hand side is in fact divisible by $BD-C^2$, and that the quotient is

$$\begin{aligned}
=\ &(-1+10\theta^2-9\theta^4)(B^2+D^2)^2\\
&+(8\theta+16\theta^3-24\theta^5)(B^2+D^2)BD\\
&+(4+8\theta^2+4\theta^4-16\theta^6)B^2D^2\\
&+(-64\theta^3-192\theta^5)(B^2+D^2)C^2\\
&+(16\theta^2-416\theta^4-112\theta^6)BDC^2\\
&+(-128\theta^4+128\theta^6)C^4.
\end{aligned}$$

3. This is found to be

$$\begin{aligned}
=&-I^2U'^2+12JU'H'+4IH'^2\\
&-\ 8IJU'\Theta'\\
&-16J^2\Theta'^2,
\end{aligned}$$

which is consequently the value of $-M$. We have therefore

$$\begin{aligned}
-\Phi'^2=\ &JU'^3-IU'^2H'+4H'^3\\
&+(I^2U'^2-12JU'H'-4IH'^2)\Theta'\\
&+\ 8IJU'\Theta'^2\\
&+16J^2\Theta'^3,
\end{aligned}$$

which is the required identical equation.

Article No. 4.—*Calculation of the Cubinvariant.*

4. We have

$$\begin{aligned} J^* &= \tfrac{1}{6}\mathfrak{C}\,.\,\mathfrak{E}-(\tfrac{1}{6}\mathfrak{C})^3-(\tfrac{1}{4}\mathfrak{D})^2 \\ &= (H-\tfrac{1}{3}I\Theta')\{IU'^2-3H'^2+(12JU'+2IH')\Theta'+I^2\Theta'^2\} \\ &\quad -(H-\tfrac{1}{3}I\Theta')^3 \\ &\quad -\Phi'^2, \end{aligned}$$

whence, substituting for $-\Phi'^2$ its value and reducing, we find

$$J^*=JU'^3+\Theta'.\tfrac{2}{3}I^2U'^2+\Theta'^2(4IJU')+\Theta'^3(16J^2-\tfrac{8}{27}I^3).$$

Article No. 5.—*Final expressions of the two Invariants.*

The value of I^* has been already mentioned to be $I^*=IU'^2+\Theta'12JU'+\Theta'^2.\tfrac{4}{3}I^2$, and it hence appears that the values of the two invariants may be written

$$I^*=(I,\ 18J,\ 3I^2\between U',\ \tfrac{2}{3}\Theta')^2,$$

$$J^*=(J,\ I^2,\ 9IJ,\ -I^3+54J^2\between U',\ \tfrac{2}{3}\Theta')^3.$$

But we have (see Table No. 72 in my "Seventh Memoir on Quantics"†)

$$\tilde{I}(\alpha U+6\beta H)=(I,\ 18J,\ 3I\between \alpha,\ \beta)^2$$

$$\tilde{J}(\alpha U+6\beta H)=(J,\ I^2,\ 9IJ,\ -I^3+54J^2\between \alpha,\ \beta)^3;$$

so that, writing $\alpha=U'$, $\beta=\tfrac{2}{3}\Theta'$, we have

$$I^*=\tilde{I}(U'U+4\Theta'H),$$

$$J^*=\tilde{J}(U'U+4\Theta'H);$$

or the function $(1,\ 0,\ \mathfrak{C},\ \mathfrak{D},\ \mathfrak{E}\between y,\ 1)^4$ obtained from TSCHIRNHAUSEN'S transformation of the equation $U=0$ has the same invariants with the function $U'U+4\Theta'H$; or, what is the same thing, the equation $(1,\ 0,\ \mathfrak{C},\ \mathfrak{D},\ \mathfrak{E}\between y,\ 1^4)=0$ is a mere linear transformation of the equation $U'U+4\Theta H=0$; which is the above-mentioned theorem.

---

† Philosophical Transactions, vol. cli. (1861), pp. 277–292.

VII. *On the Development of Striated Muscular Fibre.* *By* WILSON FOX, *M.D. Lond., Professor of Pathological Anatomy at University College, London. Communicated by Dr.* SHARPEY, *Sec. R.S.*

Received June 15,—Read June 15, 1865.

A CORRECT knowledge of the structure of the animal tissues has long been recognized as an almost essential preliminary to a full comprehension both of their physiological functions and also of the phenomena presented by disease, and the aid afforded in an inquiry into adult structure by the study of the processes of embryological formation has been fully appreciated.

While, however, the mode of growth of most of the tissues in question has been more or less completely elucidated, the development of striated muscular fibre has still remained a subject of considerable uncertainty, regarding which the most varied and even opposing views have been brought forward by observers who have made it an object of research. Feeling desirous, on pathological grounds, of attaining to some fixity in my own opinions on this question, I have during some months made it a subject of renewed study, and with results, which may, I venture to hope, assist at least to an elucidation of some of the points in dispute.

My observations have been conducted upon the Tadpole, Chick, Sheep, and human embryos at various stages of growth; and I hope to be able to show that the processes observed are essentially identical in all these classes.

Tadpoles (which offer by far the easiest objects for this investigation) are best examined immediately after they have emerged from the egg. The examination is much facilitated by placing them for a few hours in an extremely dilute solution of chromic acid ($\frac{1}{8}$ to $\frac{1}{12}$ per cent.), or (what is far better) in solutions of bichromate of potash of from 1 to 4 per cent. They should subsequently be immersed in Beale's carmine and glycerine solution [*], which renders the nuclei more apparent. The embryo chick is also best examined after immersion for a day or two in weak solutions of bichromate of potash (chromic acid is unsuitable for these preparations), and subsequent staining with Beale's solution. Sheep larger than $\frac{1}{2}$ an inch may be examined after preparation in chromic acid of from $\frac{1}{8}$ to 1 per cent.; at earlier stages either bichromate of potash or a mixture of alcohol, glycerine, and water forms a good medium; but in all instances I have found Beale's carmine an excellent help in this investigation. The structure of the early stages of the muscular fibre of the Tadpole may be investigated with a magnifying power of

---

[*] How to Work with the Microscope, p. 201.

600 diam. linear. I have, however, found that it is best to use a power of 900 for this purpose, Powell and Lealand's $\frac{1}{12}$ object-glass with eyepiece No. 2 giving a much clearer view of many points than can be obtained with lower powers.

For the proper investigation of the earliest stages in the Chick and Mammalia I regard a power of at least 900 as essential, and many points can only be satisfactorily elucidated with a power of 1250 or 1850 diam. lin. I have used for this purpose a $\frac{1}{25}$ object-glass of Powell and Lealand's, respecting the value of which I can endorse all that has been said in its favour by Dr. LIONEL BEALE.

In the Tadpole, immediately after quitting the egg, there will be found at the extremity of the tail muscles in all stages of development. These are represented in Plate V. figs. 1 to 9.

The earliest forms which indicate any differentiation from the round cells of the embryo are indicated by the appearance of oval bodies measuring from $\frac{1}{500}$ to $\frac{1}{800}$ of an inch in length with a breadth of $\frac{1}{1000}$ to $\frac{1}{1500}$. They contain a clear oval nucleus, measuring $\frac{1}{3000} \times \frac{1}{2000}$ of an inch in its longer and shorter diameters respectively. The remainder of this body is densely filled with black pigment-granules and glistening scales and masses, regarding which I have no further observations to offer.

I am disposed to term these bodies cells, not that I have been able to see around them a well-defined membrane, such a structure not becoming apparent until a somewhat later stage of their development; but their outline is so sharply defined, they alter their shape so little under moderate pressure, and form such distinct isolated anatomical elements, that I believe that a wall must exist around them even at this earliest stage, especially as one can be proved to exist at a period very little later in their development, and to which the transition only takes place by insensible gradations*. As this, however, is still a subject of considerable discussion among anatomists†, I can only give these reasons for my opinion with considerable diffidence. I have never observed any earlier stages of these bodies, nor any appearances of the building up of granular matter around a nucleus, and I believe them to result from the first differentiation of the round formative cells of the embryo,—bodies around which there is an almost equal difficulty in proving the existence of a cell-wall, but which maintain their individuality and uniformity of size and structure both under the condition of mutual pressure, and also when artificially separated. These structures, which with the above explanation I shall, for convenience sake, call cells, then elongate, so as to attain a considerable length without any necessary alteration in the apparent size of the nucleus, which ordinarily maintains a central position in relation to the long diameter of the cell; but laterally, as seen in profile, it is often observed to be situated near the border of the transverse diameter. In other cases (Plate V. fig. 2) the nucleus appears nearer to one extremity; sometimes it may be considerably elongated (as if showing a tendency to commencing division (Plate V. figs. 3 & 4)), and occasionally opposite to it there may be a bulging in the outline of the cell.

---

* On reexamining some of my preparations after preservation for twelve months in strong glycerine, I find that in some of these early cells the contents have shrunk, and that a membrane has become quite distinct around considerable portions of their outline.—June 6, 1866.

† See especially M. SCHULZE, "Ueber Muskelkörperchen und das was man eine Zelle zu nennen habe," REICHERT und D. B. REYMOND'S Archiv, 1861.

On the other hand, the elongation of the cells may be accompanied throughout by a multiplication of the nuclei contained in their interior, giving rise to forms such as are represented in Plate V. figs. 6, 7, 8, 9. By far the most ordinary condition which I have seen, has been that the long diameter of the nucleus lies parallel to that of the cell; but in a certain number of cases, at least in those where two or more nuclei have existed in its interior, they have been placed with their longer axis transverse to that of the cell (see Plate V. figs. 8, 9).

When the primary muscle-cell, whether with or without multiplication of its nuclei, has thus become elongated to a certain extent*, a change in its structure becomes apparent. Usually at one side a part appears lighter than the rest, and in this position sometimes a longitudinal, sometimes a transverse striation makes its appearance, or occasionally both longitudinal and transverse striation appear simultaneously. The contrast between this portion (which when seen in profile is observed along the entire border of the cell) and the dark pigmented condition of the remainder of the cell-contents is so great as in some cases to lead almost to the supposition that it is a band of striated matter laid in apposition with and external to the cell; and this is especially the case in the very earliest stages, when the altered part, as seen in profile, appears extremely narrow. I measured it (Plate V. fig. 9) at a period when it was only $\frac{1}{25000}$ inch in transverse diameter. At a later stage (as in Plate V. figs. 5, 8, & 10) it will be seen that the change is one really affecting the cell-contents; there is no sharp line of demarcation between the altered and unaltered portions, and over the former grains and granules of pigment are seen scattered, but to a much less degree than is observed in the remainder of the cell-contents.

Gradually the pigment diminishes in the cells, and they may then be said to be separable into two portions, one striated longitudinally and transversely, the other granular, and more or less pigmented, and in this latter portion one or more nuclei are contained. At this stage a distinct membrane may be seen bounding the granular portion, as in Plate V. fig. 11. I believe that in the cases where the membrane can only be distinguished on one side of the structure, its apparent absence on the other is only the result of the position in which the object is seen; for if the membrane (which is very thin and delicate) lies in close apposition to the striated portion, its separate outline will be quite undistinguishable; and I am confirmed in this belief by the fact, that often in the same preparation, and at stages not much further advanced, cells can be found on which a membrane can also be seen on the other side of the striated portion (when seen in profile), and separated from it by a distinct space which is filled with the same granular and pigmentary matter as that which occupies the portion of the cell which is free from striation, and which may be seen, on altering the focus, to be diffused, but much less thickly, over the surface of the striated part; so that, to my own mind, the conclusion is unavoidable, that the membrane, which can be thus distinctly seen in profile at the edges of the fibres, encloses a space occupied (1) by one or more nuclei, (2) by a substance striated both longitudinally and transversely, and (3) by amorphous transparent matter containing suspended in it a varying amount of granules and pigment. Sometimes a nucleus may be seen on each side of the striated portion, in which case the membrane and granular contents can be seen to extend continuously over the whole structure (see Plate V. fig. 13).

---

* I have, to avoid repetition, given the measurement of these figures in the special description of them at the end of this paper.

In some cases, when a muscle-cell at an early stage of its development contains two or more nuclei, it shows a tendency to division, which is evidenced by an imperfect constriction between the nuclei, this constriction being apparent on that side only of the cell which contains the nuclei, and not affecting the striated portion, if the latter change has already made its appearance within the cell. At later stages, when the fibre has become more elongated, and the nuclei are further removed from each other, there is always a depression in the outline of the membrane between the nuclei, and this may sometimes proceed to a considerable depth, but never, as far as I have observed, to a complete constriction and separation between the different nuclei (see Plate V. figs. 9, 10, 14, 16).

There is a considerable difference in the number of the nuclei contained within the membrane. They may sometimes be very numerous, and the breadth of the fibre is usually proportioned to the number of the nuclei. At other times a long cell may contain only two or three nuclei; and the difference appears to depend on the multiplication of the nuclei occurring at variable periods in the development of the fibre. Thus figs. 8, 9, 10, and 17 illustrate progressive stages of this process in those rarer cases in which the nuclei are found lying across the long diameter of the fibre; while figs. 7, 11, 12, 14, and 16 are instances of fibres, or portions of fibres where many nuclei exist within the membrane.

On the other hand, during the early stages of development, instances are found, with even greater frequency, in which a very long fibre, much narrower than the others, has only a single nucleus attached to it throughout its whole course (Plate V. figs. 18 & 19 represent front and profile views of this condition). With a high magnifying power it may in these cases be distinctly seen that a delicate membrane, often separated somewhat from the nucleus by granular contents, limits the outline of the fibre, on which its prolongation can often be traced to some little distance from the nucleus.

These fibres often lie imbricated closely together, and in their earlier stages they may often be seen presenting a spindle-shaped appearance (like Plate V. figs. 24 & 25, from the Chick); by which I think that the inference is further justified that these fibres may be regarded as having been produced by the continuous elongation of cells such as are represented in Plate V. figs. 3, 5. In one instance, represented in Plate V. fig. 20, I found a fibre dividing, and I could distinctly trace a delicate membrane outside the nuclei which lay on the fibre contained on each of the divisions*.

As development advances, the amount of space occupied relatively by the granular portion of the contents of the membranous envelope diminishes, and its place becomes gradually occupied by striated matter. A membrane may still be traced over the whole structure; and in all the instances which I examined, the nuclei were situated between the membrane and the striated portion, surrounded by a little dimly granular material. Plate V. fig. 21 represents this condition from the upper part of the tail of a Tadpole one week old, when, though seen in profile, it will be observed that the structure has all the characteristics of adult muscular fibre.

The investigation of the earlier stages of muscle in the Chick presents much greater difficulties than in the Tadpole, owing both to the smaller size, and also to the extreme delicacy of the structures concerned.

The first differentiation from the round formative cells of the embryo which I have observed commences from the second day of incubation. At this period there are found in the dorsal region oval bodies such as are depicted in Plate V. figs. 22, 23, fig. 22 measuring $\frac{1}{1190}$ of an inch in length by $\frac{1}{5555}$ of an inch in breadth, and containing a nucleus (in which a nucleolus is often but not invariably seen) of $\frac{1}{6000} \times \frac{1}{7000}$ of an inch.

These bodies are dimly nebulous; they have a distinct, clear, well-defined outline, but they cannot be seen to be surrounded by a membrane. The nucleus is often granular, and its outline is particularly well defined.

Almost simultaneously (*i. e.* after forty-eight hours of incubation), appears a series of forms like figs. 23, 24, 25 (Plate V.)—bodies tending to become fusiform, and of which I believe fig. 23 to represent the earliest stage. These also have in most cases a well-defined outline, and contain a large nucleus which is particularly well defined (Plate V. figs. 24 & 25 represent the appearances most commonly seen at this date, fig. 25 being a similar structure to fig. 24, but seen in profile). For the same reasons as I stated with regard to similar structures in the Tadpole, I look upon these bodies as cells; and the impossibility of distinguishing any isolable membrane arises, I believe, only from its excessive tenuity. They gradually tend to become much elongated and tapering at their extremities, and at this stage form a continuous tissue (as seen at Plate V. fig. 26), in which, though these bodies lie in close apposition, the outlines of each are distinctly maintained. In some of these bodies at this stage, two nuclei are seen (Plate V. fig. 27), but this does not appear to be the rule in the Chick.

Even at this early stage there may sometimes be seen a faint striation of portions of the cell-contents, usually appearing first in the form of longitudinal striæ (as seen in Plate V. fig. 25–27, figured in profile).

By the commencement of the third day of incubation a further change has appeared in these bodies, as shown in figs. 29 & 30 (Plates V. & VI). They have become much elongated, forming long fibres, in which both a longitudinal and often a transverse striation are apparent; and towards the centre of the long axis of each of these fibres appears the nucleus, external to which is a distinct membrane, which can often be seen prolonged upon the fibre for some distance. These fibres form a dense tissue, the enlargements opposite the nuclei fitting into the narrower portions of adjacent fibres. Sometimes intermediate stages are seen between these and the earlier spindle-shaped cells (as in Plate V. fig. 28).

---

* Kölliker has also seen a division of the fibres in the tail of the Tadpole, but does not mention whether he observed the membrane thus disposed (Gewebelehre, p. 102).

From the fourth to the fifth day a further change in the fibres is observed, which consists in the multiplication of the nuclei in their interior (see Plate VI. figs. 31–34).

At this stage the presence of a membrane enclosing the nuclei is very apparent. The nuclei form groups of two, three, four, or more in number, and vary somewhat in size. They are seen to have very distinct nucleoli, and are surrounded on all sides, except where they lie in apposition with the striated portion, with a granular nebulous matter, which may often be seen contained under the membrane, surrounding the narrower portion of the fibre. Figs. 31 & 32 (Plate VI.) are profile and front views of fibres, with a group of nuclei situated upon them and enclosed by a membrane which, though of considerable tenuity, is sufficiently defined to give a sharp double contour to the fibre. At fig. 34 (Plate VI.) the nuclei may be seen lying in various positions on the fibre, enclosed by a very distinct membrane, which at *a* is thrown into folds across the surface of the fibre. After the fifth day the multiplication of the nuclei proceeds to a much greater extent, and is attended with an increase in thickness of the striated portion of the fibre. Thus figs. 36 & 37 (Plate VI.) represent fibres from a Chick at the seventh and eighth days, as seen in front view and profile, and in which the conditions are similar to those previously observed, with the exception of such differences as arise from the increase in thickness of the fibre. The continuity of the external membrane is very noticeable, especially when it extends over the bulgings created by the groups of nuclei.

I have found the process of development in the Sheep to proceed in precisely the same manner as in the Tadpole and Chick. Figs. 38–44 (Plate VI.) represent forms which I have seen, and which are almost precisely identical with those seen in the Chick. The process of early growth can be best observed in the budding extremities of embryos of half an inch in length; but the multiplication of the nuclei, as seen in fig. 44, proceeds until the embryo is 4 or 5 inches long.

The earliest period at which I have examined the human embryo was at six weeks. I then found structures like figs. 45 & 46 (Plate VI.), which will be seen to correspond in all particulars to figs. 18 & 19 (Plate V.), from the Frog, figs. 29 & 30, from the Chick, and figs. 39 & 40, from the Sheep. I have not succeeded in obtaining embryos between the sixth week and the third month. By the latter period the muscles have for the most part acquired their adult structure, though the fibres are very much narrower.

The development of the muscular structure of the heart differs in some remarkable particulars from those of the extremities. Three points are noticeable in the fibres of the fully-formed heart:—1, the small size of many of the fibres; 2, the apparent absence of a sarcolemma; and 3, anastomoses between and occasional branching of the fibres.

If the heart of a Chick be examined after twenty-four hours of incubation, it will be found to consist chiefly of round cells, a few fusiform having made their appearance, and some stellate cells being also present. The stellate cells become more numerous after forty-eight hours of incubation, and by the third day large tracts of the tissue of the heart are seen to consist of these cells, which anastomose freely with one another in all directions*. Fig. 47 (Plate VI.) represents these cells at this period. They are most irregular in size and shape, giving off processes in all directions, which are of very variable thickness, and which often unite with those given off from other cells. Their contents are very granular, and there are some very indistinct appearances of striation in them. Their outline is very sharply defined (at least after the use of a solution of bichromate of potash), and around many of them I could trace a distinct double contour. Their nuclei also are very variable in size, and very irregular in position, sometimes having a situation nearly central in the cells, in other places occurring in groups upon the prolongations (*b*, fig. 47, Plate VI.).

By the fourth day they form a more continuous tissue (Plate VI. fig. 48), interlacing in all directions and giving rise to an extremely complex structure, composed of trabeculæ crossing one another in all directions, in which, in parts, the origin from the earlier stellate and anastomosing cells can still be seen. The nuclei are scattered very irregularly over these structures. The trabeculæ are all at this period very distinctly striated, the striation being more marked in the longitudinal than in the transverse diameters, and the tissue is extremely granular.

The increasing complexity of structure renders it difficult to follow with any certainty the further development of this structure after the fourth and fifth days of incubation; but from the fifth to the eighth day there appear, in addition, numerous elongated bodies, sometimes single, sometimes divided at their ends, and containing one or more nuclei, dimly granular throughout, and having at these periods no traces of striation, and presenting in the majority of instances (except when divided at their ends) the strongest possible resemblance to organic muscular fibre. They appear to be unconnected with the interlacing network formed by the stellate cells last described, but I have not been able to trace their further destination.

Conclusions.

It will be seen from the foregoing description that I regard the development of muscular fibre as a process which consists in a definite series of changes, commencing in the cells of the early embryo. I have already adduced the reasons which dispose me to retain this term for these very distinct anatomical structures, and in their later stages I regard them as possessing all the essential elements of a cell* (see Plate V. figs. 6–13, from Tadpole). This, however, is a question on which the opinions of different observers seem at present scarcely reconcileable, and therefore it is only possible for me here to state my individual views as to their nature. The next most noticeable feature which is to be observed is the change which takes place in the *interior* of these bodies,—a portion of their substance undergoing a conversion into a material which has all the recognized visible characters of muscular tissue, while the nucleus continues free and external to the striated portion, the whole being surrounded by a membrane. This membrane I regard as the sarcolemma, as its presence can be traced with high magnifying powers through every gradation of development, from almost the earliest stage, to that of fully-formed muscle; and I am therefore disposed to regard it as produced by an extension of growth, including an increase in thickness of the outermost layer (whether or not this be termed cell-wall) of the primitive cell. That this membrane is not demonstrable in the fibres of the heart at later stages, may, I think, possibly be due to its exceeding tenuity rather than to its absence; and as the position of the nuclei in relation to the fibre is similar to that found in other muscular tissue, it appears to me probable that the whole structure is held together by some limiting wall; since it is seen that in all stages of development the nuclei are external to the striated portion, which appears to be formed by a gradual conversion of fresh material accumulated during growth within the sarcolemma, and probably under the influence of the nuclei as nutritive centres. These latter seldom or never appear to be imbedded within the fibres, though here and there, in the muscular fibre of the adult Frog, this may occasionally be the case.

---

* These are too numerous, and occupy too large a relative amount of tissue, to be concerned simply in the formation of nervous ganglia; moreover their subsequent development shows them to be early stages of muscular fibre.

It will be seen that my descriptions accord very closely with those of LEBERT, REMAK, and KÖLLIKER. The early stages in the Chick and Tadpole (Plate V. figs. 2–6, & fig. 22) correspond very closely with M. LEBERT'S figs. 11, 21, & 26†. After this stage there is, however, some discrepancy between M. LEBERT'S and my descriptions, as there is also in the period at which he states the differentiation in the Chick to commence. I have found it most distinctly at the end of forty-eight hours of incubation in the dorsal region; M. LEBERT states that no traces of muscular fibre are formed before the fifth day,—a period at which I have found the process considerably advanced. M. LEBERT'S description of the development of the fibres of the heart differs considerably from mine.

My observations correspond closely with those of Professors REMAK‡ and KÖLLIKER§, and I am glad to know that the opinions at which I have arrived agree with those which have been maintained by these distinguished observers. There is, however, one point on which I would venture to express an opinion differing somewhat from that held by Professor Kölliker, though the question is of comparatively minor importance; and instead of regarding, with him, each fibre as a single many-nucleated cell, I should be disposed to consider it as a structure representing a series of many potential cells*, which have, however, never separated, their division after the multiplication of their nuclei having been prevented by the fibrillation longitudinally (as shown by striation) of a portion of their contents, while the sarcolemma would thus represent the united membranes of many cells which have been engaged in the formation of the fibre. This view may suggest that of Schwann's†, of which it may be regarded as a modification; but the differences between his descriptions (in which he represents a fibre as formed by the fusion of a series of *preexistent* and *independent* cell-structures) and mine will be at once apparent. Of course, when a fibre, as in the early stages, contains only one nucleus, it must then be regarded as a single cell. With regard to the opinions entertained by Margo‡, that the growth of muscular fibre is due to the fusion of spindle-shaped cells, it is one which for a long time I was disposed to entertain; and figures may often be obtained in breaking up the fibres of sheep of 3 or 4 inches in length, after hardening in chromic acid, which would seem strongly to support this view. Such appearances are, however, I believe, due to three causes. In the first place, fibres in very different stages of development lie frequently in close apposition, and when partially separated, the less mature fibre may often look like a portion of a broader and more fully formed one. Secondly, under the same circumstances nuclei with a portion of the sarcolemma may be detached from the surface of the fibre, and, when hanging from it, may present a great resemblance to spindle-shaped cells. Thirdly, capillaries developing on the external surface of the fibres have a most deceptive resemblance to long spindle-shaped cells, into which indeed they can sometimes be broken up. It also militates very strongly against this view that, in tearing up adult muscles hardened in chromic acid, the nuclei are never found in connexion with the fibrillæ, but are always separated as distinct bodies; often with a little granular matter around them, the remains of the original cell-contents by which they are surrounded within the sarcolemma. Of any spindle-shaped bodies or anastomoses from processes given off from the nuclei *within* the sarcolemma which have been described by some later observers§, I have seen nothing either in adult or in fœtal muscles.

---

* See note, p. 102.

† Ann. Sciences Nat. 3rd series, vol. ii. 1849.

‡ Froriep's Notizen, 1845; and Entwickelung der Wirbelthiere, Taf. xi.

§ Zeitsch. Wiss. Zool. ix. Gewebelehre, 1862.

It would, however, be out of my province in this place to attempt a criticism of the labours of the very numerous writers‖ upon this subject, or to show wherein the views which I have been led to entertain agree with or differ from theirs; but I think it may be desirable for me to refer to two papers which have already appeared at the meetings of this Society, and in which the views expressed by their authors are somewhat at variance with those which my observations have led me to form.

---

* Though this may appear almost a truism, yet I think it a consideration of some importance in relation to some of the pathological processes affecting muscle.

† Microscopical Researches, Syd. Soc. Trans. p. 137.

‡ Quoted by Kölliker, Gewebelehre, ed. 1863.

§ Leydig, Müller's Arch. 1856; Welcker, Zeit. Rat. Med. viii.; Boettcher, Virch. Arch. xiii.; Sczelkow, Virch. Arch. xix.

‖ See Kölliker's Gewebelehre, ed. 1862.

Mr. SAVORY'S* observations were made on the dorsal muscles of embryos at a period when their development is already considerably advanced. It will be seen that my figures of the Chick and Sheep in more advanced stages correspond very closely to his drawings, though I have not thought it necessary to multiply figures of the enlargement and maturation of the fibres, as these have been already most ably depicted in the paper in question.

There is one other observer, whose distinguished position entitles his observations to the greatest respect, but with whose views my own cannot be brought to correspond. I refer to Mr. LOCKHART CLARKE, who, in vol. xi. of the 'Proceedings' of this Society†, has advanced the view that the development of the fibre proceeds by a fibrillation of blastema upon free nuclei. There is at once a discrepancy between Mr. CLARKE'S observations and mine as to the period at which a distinct differentiation of muscular tissue occurs, he placing it at the fifth day of incubation, while I have found it distinctly advanced after forty-eight hours. Mr. CLARKE regards such figures as 24 & 25 in my Plates as the result of the deposition of granular matter around a nucleus, the granular matter forming a fibre and embracing the nucleus; I regard them as the further elongation of such cells as figs. 22 & 23 represent. I have already given my reasons for regarding these structures as possessed of a sharp limiting outline, though, of course, in breaking up such delicate structures for microscopic examination, free nuclei surrounded by more or less granular matter will frequently be more numerous objects in the field than the complete cell-forms, which are often comparatively rare and difficult to find, but which I regard, as will be seen from the foregoing, as the essential element in the development of these structures.

DESCRIPTION OF THE PLATES.

PLATE V.

Figs. 1–21 represent the development of muscular fibre in the Tadpole, × 900 diameters.

Fig. 1. First appearance of muscular tissue at extremity of tail of newly-born Tadpole. Outline well defined, though membrane not apparent. Measures $\frac{1}{1000}$ of an inch in length, $\frac{1}{2000}$ of an inch in breadth. Nucleus measures $\frac{1}{3000} \times \frac{1}{5000}$ of an inch.

---

* Philosophical Transactions, 1855.

† Also in Microscop. Journ. 1862.

Figs. 2–5 are further stages of the elongation of fig. 1; fig. 5 measured $\frac{1}{450}$ of an inch in length, $\frac{1}{1000}$ of an inch in breadth. Their nuclei averaged $\frac{1}{1000}$ of an inch in length, $\frac{1}{3000}$ to $\frac{1}{5000}$ of an inch in breadth. In fig. 4 a faint appearance of striation is becoming visible, which is much more apparent in fig. 5, where it can be seen that the striation passes by insensible gradations into the contents of the rest of the cell.

Fig. 6–10 are cells with many nuclei. In figs. 8, 9, & 10 striation is already appearing.

Figs. 11–13 are cells whose pigment has partially disappeared, and around which a membrane is distinct. The membrane is best seen on the striated side of fig. 11 (seen in profile). The contents of the cells are seen to be differentiated into a granular portion and a striated. The nuclei are found in the former. Length of fig. 13, $\frac{1}{410}$ of an inch, breadth $\frac{1}{1000}$ of an inch; breadth of central band, $\frac{1}{5000}$ of an inch; length of nuclei, $\frac{1}{2000}$ of an inch; breadth of nuclei, $\frac{1}{3600}$ of an inch.

Figs. 14–16 show portions of fibres in more advanced stages of same process. Total breadth of fig. 16, $\frac{1}{2400}$ of an inch; breadth of striated portion, $\frac{1}{4000}$ of an inch. The membrane with granular contents within it can be traced over the whole of this latter fibre.

Fig. 17 is a further stage of figs. 8–10, where the nuclei lie transversely to the fibre.

Figs. 18 & 19 are front and profile views of fibres produced by the elongation of cells like fig. 5; fig. 19 is seen surrounded by a distinct double outline. Width of whole, including membrane on each side, $\frac{1}{5000}$ of an inch; width of striated portion, $\frac{1}{6666}$ of an inch. Such fibres may narrow at their extremities to a width of $\frac{1}{12000}$ of an inch.

Fig. 20. Instance where a divided fibre was found in the tail of the Tadpole; the membrane (sarcolemma) was seen continued on each division.

Fig. 21. Fibre from the tail of a Tadpole one week old; striated portion has greatly increased in proportion to rest of contents of sarcolemma; nuclei are seen within sarcolemma, but external to striated portion. Width of whole, $\frac{1}{1100}$ of an inch, of striated portion, $\frac{1}{1250}$ of an inch.

PLATE VI.

Figs. 22–38 represent the development of muscular fibre in the Chick × 1850 diameter.

Figs. 22–26 stages found after forty-eight hours of incubation.

Fig. 22. Measures $\frac{1}{1190}$ of an inch in length $\times \frac{1}{5555}$ in breadth. Diameter of nucleus $\frac{1}{6000} \times \frac{1}{7000}$ of an inch. Length of fig. 24 $\frac{1}{1500}$ of an inch; breadth $\frac{1}{3000}$ of an inch.

Figs. 27 & 28. From Chick after seventy-two hours' incubation. Length of fig. 28 $\frac{1}{750}$ of an inch; breadth at *a* $\frac{1}{5000}$ of an inch, at *b* $\frac{1}{12000}$ of an inch.

Figs. 29 & 30. Chick from fourth to fifth day. The nucleus now appears prominent on the fibres with some granular matter around it, the whole being enclosed by a membrane. Width of striated portion $\frac{1}{20000}$ to $\frac{1}{16000}$ of an inch; width of nucleus $\frac{1}{4500}$ of an inch.

Figs. 31 & 32. Fibres from Chick at fourth and fifth days. Width of whole fibre (fig. 31) at *a* $\frac{1}{8000}$ of an inch; width of striated portion $\frac{1}{22000}$ to $\frac{1}{16000}$ of an inch, width of whole enlargement at *b* $\frac{1}{2500}$ of an inch.

Figs. 33 & 34. Fibres from sixth to seventh day. Sarcolemma now very apparent. Width of striated portion of fibre (fig. 34) $\frac{1}{12000}$ of an inch.

Figs. 36 & 37. Fibres from Chick at eighth day. Show great increase of nuclei. Width of fibre (fig. 37) at *a* $\frac{1}{6666}$ of an inch.

Figs. 38–41. From Sheep half inch in length. Length of fig. 38 $\frac{1}{1200}$ of an inch, breadth $\frac{1}{5500}$ of an inch. Width of fig. 39 at *a* $\frac{1}{3800}$ of an inch, at *b* $\frac{1}{8000}$ of an inch, at *c* $\frac{1}{16000}$ of an inch. Length of nucleus in fig. 40 $\frac{1}{3300}$ of an inch, breadth $\frac{1}{4600}$ of an inch.

Fig. 41. Shows elongation of a cell (such as fig. 38) with multiplication of its nuclei and commencing striation, and corresponds to figs. 11 & 27 from Tadpole and Chick.

Figs. 42–44. From Sheep one inch long. Width of whole fibre (fig. 43) at *a* $\frac{1}{4000}$ of an inch; of striated portion $\frac{1}{8000}$ of an inch. The sarcolemma can be distinctly seen surrounding these preparations.

Figs. 45 & 46. From human embryo of six weeks. These are magnified only 690 diameters, and consequently show less distinctly than those of the Sheep and Chick, the continuity of the sarcolemma outside the nucleus and fibre. Width of fibre (fig. 45) at *b* $\frac{1}{20000}$ of an inch; of nucleus $\frac{1}{7000}$ of an inch.

At fig. 46 is seen a commencing multiplication of the nuclei within the sarcolemma.

Fig. 47. Stellate cells from heart of Chick between second and third day. Around some a double contour can be seen. ×1850 diameters.

Fig. 48. Anastomosing fibres from heart of Chick between fourth and fifth days, ×1850 diameters.

Fig. 49. Spindle-shaped cells from heart of Chick from fourth to eighth days.

VIII. *On the Structure and Development of the Skull in the Ostrich Tribe.* *By* WILLIAM KITCHEN PARKER, *F.Z.S.* *Communicated by Professor* T. H. HUXLEY, *F.R.S.*

Received February 23,—Read March 9, 1865.

Introduction.

THE present paper is intended to be the first of a series on the Anatomy of the Vertebrate Skull; and I have chosen the cranium and face of the Ostriches as a starting-point, principally because of the mid position of these birds in the vertebrate subkingdom, and, in some degree also, because of their *generalized* character. Indeed, to any one familiar, on the one hand, with the structure of the skull in the higher mammalian types, and on the other with that of the osseous fishes, the skull of an Ostrich is interesting and important in a very high degree; serving, at it does, as a *key* to open up the meaning of parts so extremely unlike as the true *homologues* in the Fish and in the Mammal often are. And further, whilst aiding the anatomist in revealing the true morphological counterparts in the highest, as compared with the lowest types, the skull of an ostrich does also form a *link* of the utmost value for connecting together that of a cold-blooded and that of a warm-blooded creature.

I hope to follow up this first paper by one on the development of the skull and face in the Common Fowl, and this for two reasons; first, because this bird is the most available, in all its stages, to the morphologist, and also because it takes us further up amongst the branches of the great *ornithic tree*; leading us by gentle gradations towards those higher types in which the feathered tribes culminate.

Afterwards the "Sauropsida," as a whole, being one of the three great primary divisions of the Vertebrata, may be investigated still more completely; then the Mammalia, and ultimately the "Ichthyopsida." I may mention that the material for these papers is not altogether wanting; but much more research is needed to make it available for the purposes of science.

Having laboured much at the Fishes, I naturally look at the skull of the Bird with the eye of an ichthyotomist: this will explain why certain terms, either new to anatomical science, or only existing in my own published papers in the Transactions of the Zoological Society, have been used. For although the true counterpart of some bone, distinct and well known as to its mere form in the lower classes, may exist in the Mammalia, yet if it be not *autogenous* in them, but existing as a mere outgrowth of some other, then the distinct bony piece of the lower type of vertebrate must have its own proper name, and cannot be described as a *process* or outgrowth.

In the present paper I shall have to speak of a bone which, although distinct in

Amphibians, Snakes, Lizards, and Birds, is a mere *palatine* outgrowth of the maxillary in Crocodiles and Mammals; working ascendingly, I call this bone (mistaken by CUVIER and most others for a "turbinal") simply the "prevomer."

A similar instance is not far to seek; for the palatine plate of the palate-bone of the Crocodile and Mammal is in certain Birds (*e. g.* the "Lamellirostres") a small but distinct ossicle; this I have called "interpalatine." On the whole, however, I have endeavoured to keep very close to the old familiar human-anatomy terms, eschewing meanwhile all those synonyms which appear to me to mislead the student who is in search of true morphological unity.

For opportunities of studying very many valuable specimens that I could not have otherwise seen, I have to thank the Council and Officers of the Royal College of Surgeons—especially Mr. W. H. FLOWER; and also Dr. SCLATER and the other Officers of the Zoological Society.

Nor must I forget to state that throughout my work I have constantly had the great advantage of the advice and cooperation of my friend Professor HUXLEY.

The Skull of the Great Ostrich (Struthio camelus, "A.").

For a description of the earliest stages of growth in the Bird's skull I must refer the reader to Professor HUXLEY'S new work on the 'Elements of Comparative Anatomy,' pp. 130–142, fig. 57, A–F.

My youngest struthious embryos are those of the African Ostrich (*Struthio camelus*); two of these were scarcely larger than a sparrow; but the head of each was 1½ inch long, whilst the shanks measured only 9 lines.

At this stage ("*Struthio*, A.") the cartilaginous skull is perfectly formed (Plate VII.), and a few of the bones which develope in it have appeared; there is no trace, however, of some very important of these bone-patches. On the other hand, the calcareous substance has begun to harden those dense webs of fibrous tissue which are destined to form the secondary bones, viz. those which have no preexisting hyaline cartilage. A considerable part of the primordial skull is a long time before it ossifies; some of it does not ossify at all; and some very important parts—the anterior third of the coalesced "trabeculæ cranii" and the anterior or lower two-thirds of "MECKEL'S cartilages"—are absorbed soon after hatching.

As a rule, the secondary bones (opercular bones, splint bones) appear first; they are not formed at random, but the fibrous matrix which becomes osseous tissue is in some degree separated into bone-territories by the intervention of somewhat looser tracts of connective tissue. It seems to be quite certain that the *diaphysial* osseous deposit, even in cartilage-bones, is at first quite external to the cartilage-cells and their progeny, and even to the intercellular substance which binds them into one clear, cheese-like mass.

But the connective tissue which enwraps hyaline cartilage (perichondrium) is at one time internal, and at another time external to the first laying in of phosphate of lime. This gives us a most important fundamental distinction between primary and secondary bones; for although the bone-layer of a cartilaginous plate or rod may never affect the cartilage-cells at all, yet it is always *inside* the perichondrium. The splint bones may enfold persistent cartilage, or this *pith* may be absorbed; whilst in other cases we find the secondary bone rambling away far from the cartilage which served at first as its model, and running up and down any aponeurotic tract that may be available for it. Splint bones are not called *secondary* because of any lateness in their appearance—they are the first to appear; but cartilage is the first, or embryonic skeleton, and in certain low Vertebrata never takes on a calcareous condition.

One important difficulty turns up in this part of our research, and that arises from the fact that certain parts of the face, viz. the pterygo-palatine arcade, ossify as early as the earliest splint bones, whilst the tissues of the embryo are still simply cellular. Careful attention to this matter has led me to see that the difficulty is not at all insuperable, and that it does not in the least affect the distinction between the two classes of ossifications. I shall explain this more perfectly in subsequent papers; yet it seemed necessary to me to premise my description of the struthious skull with some remarks on the histology of the ossifying structures.

I must remark, further, that in studying RATHKE'S beautiful researches (by the help of Professor HUXLEY'S translations), I have been often confused by the use of the term "cartilage," both for condensed tracts of fibrous tissue, and for the true, or hyaline cartilage. The loose use of this term in RATHKE'S most invaluable works makes it necessary that those who follow him should repeat his observations in every possible instance. Holding this one point of weakness in memory, no better guide can be had.

I have also been led to differ very considerably from this truly great anatomist in the determination of the homologous bones in the various classes. Professor HUXLEY'S researches have shed much light upon this matter, but I find still further correction needed.

Returning to the earliest of the struthious skulls, we find that the hyaline cartilage which has been formed in the primordial membranous brain-case is perfectly continuous (Plate VII.). And this is not only the case with the proper cranial chamber, but parts truly *facial* are in nowise differentiated from those which belong to the cranium proper. Thus the auditory capsules are continuous with the occipital cartilage behind and below, and with the posterior sphenoidal region in front and below. The anterior sphenoidal cartilage passes (in front) continuously into the upper parts of the lateral ethmoids above, and into the great middle ethmoidal plate below (Plate VII. figs. 1 & 2, *eth.*, *o.s.*, *p.e.*, *p.s.*).

These two pairs of sense-capsules, the olfactory and the auditory, are not the only parts which are continuous, as cartilage, with the cranium; but the primordial, or fundamental part of the intermaxillary apparatus (Plate VII. figs. 1 & 2, *p.n.*) has not shown the least disposition to segment itself from the vertical ethmoid, and indeed it is one with the continuous orbito-nasal septum. On the other hand, the palatine has been long differentiated from the lateral ethmoid, and the quadrate cartilage from the front, and the stapes from the hinder part of the auditory capsule (Plate VII. fig. 4, *pa.–q.*).

The cartilaginous skull of the Ostrich is at this stage perfectly formed; yet the intercellular substance is scanty, and the whole structure is very friable: its shape will undergo but little change.

Beginning at the basioccipital region, we find a large conical mass of notochord (Plate VII. figs. 1, 2 & 6, *n.c.*) reaching only halfway to the deep cavity of the "sella turcica;" this mass is enclosed in the thick investing cartilage, which is deficient at the top and thick below, and has its posterior half enveloped in the large, transversely oval, occipital condyle. In front of this condyle, both above and below, there is a thin layer of bone (Plate VII. figs. 1 & 2, *b.o.*); the upper layer is encroaching upon the cartilage downwards, and the lower lamina upwards, but there is a thick mass of untouched cells between them. The upper lamina of bone is oval, the lower lozenge-shaped; the latter reaches in front to a trifoliate mass of cartilage, which has almost filled in the original space between each half of the investing mass, just up to the point where each cranial "trabecula" is given off. There is in front of this secondary growth of cartilage a true pituitary "fontanelle" (Plate VII. fig. 4, *p.t.s.*) still remaining; it is oval, and about half a line in fore-and-aft extent. In the cranial floor, however, the cartilage is still more deficient; and the anterior half of the "investing mass," viz. that which belongs to the posterior sphenoid, is separated by a fissure (Plate VII. fig. 1, *b.o.*).

It will be seen in my subsequent papers how all these minute particulars bear upon the structure of the skull in other classes, and how they look back upon the earlier stages of even the ornithic skull. The exoccipital (Plate VII. figs. 1, 2, 4 & 6, *e.o.*) does not begin at two points, but takes advantage of the cartilaginous selvedge formed by the "foramen magnum;" it spreads equally inwards and outwards, embracing the thick ascending plate; the laminæ eventually meet each other in the substance of the cartilage. At this stage the exoccipital is a very small patch, notched in front, where it half encloses the anterior condyloid foramen (Plate VII. figs. 1 & 2, 9.); it does not reach the chink for the vagus nerve. The whole of the broad, flat superoccipital cartilage, and the whole of the periotic capsule (Plate VII. figs. 1, 2 & 6, *s.o.*, *a.s.c.*, *p.s.c.*, *h.s.c.*) is still free from ossific deposit; the former part is already very thick, but the cartilage covering the large semicircular canals is thin, and reveals their form very perfectly on the wide vertical occipital plane (Plate VII. fig. 6). These are the posterior and horizontal canals, but the largest of the three is the anterior, and this is entirely seen within the cranial cavity (Plate VII. fig. 2); the obliquity of the whole capsule is so great that this canal is tilted backwards into the superoccipital region, and receives, ultimately, much of its bony investment from the superoccipital piece.

The sinus canal (Plate VII. figs. 2 & 5, *s.c.*), near the junction of the posterior semicircular canal with the upper edge of the superoccipital cartilage, is very wide but short; it is well seen within, at its commencement; and without, at its termination.

The fourth and last ossific centre to be described, as at present occupying the cranial cartilage, is the basisphenoid (Plate VII. fig. 2, *b.s.* & *r.b.s.*): this bone begins, at first, as an upper and a lower lamina. But unlike the basioccipital, the laminæ are not originally in the same vertical line; for the upper deposit takes place in the fundus of the deep "sella turcica," and the lower appears below the middle of the anterior sphenoidal cartilage (Plate VII. fig. 2).

This anomaly arises out of a disposition of the cranial structure in the embryo of the Bird, which has, from vicious interpretation, been the cause of much perplexity and error. In fig. 57, F', p. 139 of Professor HUXLEY'S "Elements," a most instructive condition of the early skull of the chick is given; at this stage the occipital region of the skull, with the enclosed "chorda," is more than half the whole length of the basis-cranii; in my earliest ostrich-embryo the cephalic part of the chorda is only one-twentieth part of the length of the skull-base. This change has arisen from the great extension of the investing mass, and of its forthstanding outgrowths, the "trabeculæ." In this young ostrich the chorda is separated from the pituitary body by a mass of cartilage equal to that which invests it (Plate VII. figs. 1 & 2); whilst the large, oval pituitary space of the earlier stage has been nearly obliterated, not only by the formation of a cartilaginous floor, but also by the convergence, during growth, of the trabeculæ themselves. In an intermediate stage between Professor HUXLEY'S fig. 57, F' and this which I describe, the pituitary space became a mere slit anteriorly; and this fissure was filled in below by a dagger-shaped band of dense cellular tissue. Whilst the edges of the trabeculæ behind were being connected together by a floor of cartilage, the same growth of cells was taking place in the interior of the dagger-shaped band, thus enlarging it, and giving to it a pith of true cartilage. The extension forward of the true pituitary floor reaches in this young ostrich to the middle of the alæ nasi (Plate VII. fig. 2, *al.n.–r.b.s.*); and that is the part which answers to the diverging point of the trabecular cornua in Professor HUXLEY'S figure 57, F': these cornua were wholly enclosed in the fronto-nasal process (*op. cit.* fig. 57, F, K). Beneath the "sella" (Plate VII. fig. 1, *p.t.s*, fig. 2, *b.s.*) the bony layer is thin; but the long style or rostrum is already wholly ossified in "*Struthio*, A;" this is of great importance to notice, for the style does not chondrify in the cold-blooded ovipara, and in typical birds greater time is allowed for the maturation of the cartilage-cells than in the Struthionidæ. The early appearance of the basisphenoid in birds has something to do with its inordinate size; for the late-appearing presphenoid in them never reaches the trabecular region below, the thick presellar part of the basisphenoid uniting with the perpendicular ethmoid; thus both of these latter bones encroach upon the presphenoidal territory. The median layer of the pituitary floor, and the thick, high, almost perpendicular walls of the "sella" (Plate VII. fig. 1, *a.cl.–p.cl.*) are as yet unossified, as is nearly the whole remainder of the cartilaginous skull at this stage.

The alisphenoid (Plate VII. figs. 1, 2 & 3, *a.s.*) is completely preformed in cartilage; and this cartilage has no membranous fontanelle, or remnant of the original membranous brain-sac; it is subpentagonal, is notched at its postero-inferior angle for the large trigeminal nerve (Plate VII. figs. 1, 2 & 3, 5), and is continuous with the periotic capsule behind, and with the sellar region of the basisphenoid below. It is convex outside, and concave within, and is of considerable thickness.

In the Ostrich-tribe and in all embryo-birds, the posterior sphenoid is further complicated by two thick outgrowths of cartilage, the anterior pterygoid processes (Plate VII. figs. 2 & 4, *a.p.*); they arise in the Struthionidæ on each side, and somewhat in front of the sella turcica, and project outwards and forwards to abut against the true, or *internal* pterygoid bones. In this stage (*Struthio*, A.) they are only slightly ossified at their base by the long inferior bony piece, which is already spreading out posteriorly.

The internal carotid arteries (Plate VII. figs. 2 & 4, *i.c.*) pierce the thick, wide investing mass opposite the anterior end of the basioccipital; close below each carotid canal, near the edge of the chondrified mass, there is already a small irregular patch of bone; this is the "basitemporal" (Plate VII. fig. 4, *b.t.*), or "lingula sphenoidalis." Between the coalesced rafters of the skull and the secondary skull-balk (Plate VII. fig. 2, *p.s.–pe.–r.b.s.*) (rostrum of basisphenoid) there is much fibrous tissue, except as we approach the anterior clinoid wall: this fissure is only slowly obliterated.

The coalesced trabeculæ maintain a pretty equal thickness to their termination in front; near the end, however, they lose their height, become broader, curve slightly downwards, and end in a rounded subspatulate manner (Plate VII. figs. 1–5, *p.n.*). After the basis cranii had recovered from its mesocephalic flexure, both the optic and the olfactory sacs approximated; and the simple, indifferent tissue between them became converted into one continuous vertical plate of cartilage with its investing perichondrium. Thus the presphenoid, the vertical, or middle ethmoid, and the nasal septum, form one continuous plate (Plate VII. fig. 2), somewhat thinner between the eyes and the turbinal coils than at the other parts, but altogether thinner than the base of the plate which was formed by the coalescence and chondrification of the trabeculæ.

The highest part of this orbito-nasal septum is the homologue of the "crista galli" (Plate VII. figs. 1, 2 & 3, *cr.g.*) of the human skull, on each side of which the olfactory lobes (1) pass to terminate inside the simple rudiments of the cribriform plate (*eth.*, *al.e.*). The hemispheres of the cerebrum only reach this point, and they lie obliquely on a pair of laminæ which grow out of the posterior half of the orbital septum. These oblong plates have their free angles rounded; each posterior angle lying a short distance from the alisphenoid, and each plate being less than half the size of the posterior sphenoidal ala—these are the orbito-sphenoids (Plate VII. figs. 1 & 2, *o.s.*).

In front of these orbital alæ the septum is notched above, and this notch passes on each side into the groove for the olfactory lobe; above these grooves the septum gives out its ethmoidal alæ (Plate VII. figs. 1 & 2): the delicate cartilages of the nasal sacs being continuous with the septum of the orbits and the nose, and also with each other.

They may, however, be described regionally; and then we have the aliethmoid (*al.e.*, *eth.*), which grows outwards and downwards to form the feeble upper and middle turbinals, the aliseptal plates (*al.s.*), which form the inferior turbinals, and the alinasal laminæ (*al.n.*), the homologues of our alæ nasi. I shall describe these parts more fully in embryos further advanced. The prenasal cartilaginous rostrum (*p.n.*) belongs to the visceral laminæ of the front, or terminal part of the head; in this stage it is at its fullest growth, and soon begin to shrink, but not before it has served as a model to the splint bones which are vicarious of it. The great general fontanelle (Plate VII. fig. 1, *o.s.–s.o.*), or space left unfinished by cartilage—the orbito-sphenoids, alisphenoids, periotic crest, and superoccipital cartilage together failing to form even half of the brain-case—has to be roofed in by the frontals, or orbito-sphenoidal splints, and by the parietals, or alisphenoidal splints (Plate VII. figs. 3 & 5, *f.p.*). These two pairs of bones are formed, as usual, in the outer layer of the embryonic "dura mater;" at this stage they are mere patches, not half the required size; they are moreover mere aggregations of minute, irregular bony points, only partially hiding the mat of fibrous tissue in which they are being deposited. The superoccipital cartilage (*s.o.*) has here no splint or interparietal piece as in the mammal, where two such ossific centres appear above the superoccipital and between the parietals. The mesencephalic region (Plate VII. figs. 3, 5 & 6, *fo.*) is still very prominent, although the optic lobes are beginning to be inferior to the hemispheres in size.

Further forward there are two other pairs of feeble bony patches, the splints belonging to the olfactory laminæ; they are the external and the upper ethmoid splints, the nasals and the lacrymals (Plate VII. figs. 3 & 5, *n.l.*).

Their present form is a small rough model of their persistent condition; they have been well differentiated in mere connective or fibrous tissue; and at this stage the lime is merely diffused through the web in small granules: such a condition, the fibrous web being rendered denser by so much lime, might easily cause these tracts to be mistaken for true cartilage, if only low powers were used in their examination. The nasals and lacrymals certainly belong to the facial category, for they are *opercular* additions to the olfactory cartilages, the *upper* surface of which would be a continuation of the cranial *floor*, if the brain were continued so far forward into the nasal region.

Before leaving the skull- and sense-capsules, I would remark that in the formation of true hyaline cartilage the cells of the orbitonasal septum do not bear a *filial* relation to those of the "trabeculæ." Each structure is preformed in simple or indifferent tissue, and the differentiation of tracts of such cellular substance into a fibrous web, or into cheese-like cartilage, is one of the first great formative processes of which we can give no account. Afterwards the growth of each region takes place by the proliferation of such metamorphosed cells, the progeny formed within the parent cells being of the same nature as their parents.

When, however, a sufficient mass of these has been formed in each region, then, whether the tract be of fibrous tissue or of hyaline cartilage, the bony metamorphosis takes place indifferently, and the distinction is lost again; the two temporary tissues, notwithstanding their very different attributes, giving place to a uniform bony structure, which, when completely formed, tells no tale of its former history.

The next parts to be described are the facial arches—visceral arches of the head; and here it will be well to attend with the utmost care to what may be really seen, rather than to what has been written upon the subject. The first poststomal arch is the most highly developed in the Ostrich, in typical birds, and in the Vertebrata generally, it may therefore be our starting-point; still it will be necessary, more or less, to study all the four arches in connexion.

In *Struthio*, A., the proximal part—quadrate cartilage, incus—(Plate VII. figs. 3–6, *q.*) is already completely segmented from that part of the investing mass which is in front of the periotic capsule, and which is indeed the basal part of its investment; for the cartilage which covers in the simple auditory sac, and that which grows round the "medulla oblongata," are both continuous with that which invests the cephalic part of the "chorda." The mandibular pedicel has its true origin along the outside of the base of the auditory sac; the pedicel of the hyoid ramus arises from the posterior part of its base, somewhat behind and below the quadrate cartilage; the second *pre*stomal arch (palatine) arises from the base of the posterior wall of the nasal sac, and the first prestomal (intermaxillary) never becomes perfectly segmented from the base of the internasal septum; the latter part, being the extreme of the series, thus keeps to a low type of growth like, but still more simple than, the mandibular arch of the Chimæroid fishes; the Lepidosiren also, and the Batrachia generally. The mandible of the Ostrich (Plate VII. fig. 3, *q.–d.*) does not show the typical form of a visceral arch so well as many of the higher birds, especially the Gallinæ; the truest form being a descending proximal part, to which is swung a long bar projecting both backwards and forwards, and which lies nearly in the same plane as the cranio-facial axis. The high development of this arch is shown in its complete separation by a synovial joint from the end of the bar in front of it—the pterygo-palatine arcade; and also in as perfect a division between the suspending portion from the long, almost horizontal bar. The long anterior part (Meckel's cartilage) has grown, as it were, at the expense of the posterior more incurved rod (the internal angular process, manubrium mallei of Mammals); and the very free joint between the quadrate and the articular portion allows this arch to form a large angle with the palatine (the rudimentary second prestomal arch) when the mouth is opened. The quadrate cartilage is large, and rather clumsily formed; its head or suspending part shows no trace of subdivision into an anterior and a posterior incudal crus; and its orbital or metapterygoid portion is large and thick. A film of bone (Plate VII. figs. 3 & 4, *q.*) has appeared under the perichondrium at the postero-external part of the shaft: on the outside this lamella is seen to be creeping on to the metapterygoid process, which is ossified continuously with the main part of the bone.

At the base of the cartilage there is a thick crescentic convexity (Plate VII. fig. 4, *q.*), the horns of the crescent looking forwards, and being very large and swollen. The head of the detached mandibular cartilage (Plate VII. fig. 3, *ar.*)—wholly unossified at this stage—is scooped to receive the convexity of the base of the quadrate; the anterior bar is very long (partly seen in Plate VII. fig. 3, above *s.a.*) and terete, gently tapering towards its blunt anterior extremity; this is MECKEL'S cartilage. The posterior bar, or internal angular process, is short, thick, and incurved. The mandibular splints are as far advanced as those of the skull; and that which overlaps the detached proximal piece (Plate VII. figs. 3–6, *sq.*) is larger than the parietal; it is lozenge-shaped, the obliquely-placed inferior angle being the largest, and running down the side of the quadrate cartilage. This splint is the true homologue of the squamosal of the Mammal, of the temporo-mastoid of the frog, and of the preopercular of the osseous fish. Outside the detached bar there are three splints, the dentary being distal, the surangular and angular being proximal (Plate VII. fig. 3, *d.s.a.a.*): on the inside there are two, the splenial, or distal piece, and the coronoid, or proximal.

The pterygo-palatine or second prestomal arch is developed after a lower type, and in a more hurried manner, and there is no free descending ray. It has been completely ossified during the embryonic *simplicity* of the cellular tissue in which it was roughly premodelled. It is not in the Ostrich composed of more than two pieces, the pterygoid behind, and the palatine in front (Plate VII. fig. 4, *p.g.–pa.*); and the proximal part, or pedicel, is not segmented from the posterior end of the palatine; it is its *orbital* process. The two bones articulate by an oblique suture, which is not persistent, being lost again in the adult bird. The ends of this horizontal divided bar differ very much; that which is formed by the palatine becoming a sharp style which interdigitates with the intermaxillary splints, whilst the connexion of the pterygoid with the quadrate cartilage is by a cup-and-ball synovial joint: the cup belongs to the pterygoid, and the ball (a very important part in a descending survey of the vertebrate skull) to the quadrate cartilage. Another synovial joint; of an oval form, and with a flattish sinuous face, appears on the inner side of the pterygoid; it articulates with a similar facet on the end of the anterior pterygoid process of the basisphenoid (Plate VII. figs. 2 & 4, *a.p.*). The splints of the pterygo-palatine rod are in a very feeble condition, the zygoma being a mere tendon, and only the jugal and quadrato-jugal (Plate VII. *j.q.j.*) being developed. Moreover, the position of these splints is very peculiar; for although in an early state of the "maxillary rudiment" the tissue in which they have been formed lay close outside the pterygo-palatine streak, yet the rapid widening of the mouth has caused the removal of the zygoma far external to the palatine (primordial) rod.

The facial flaps which grow down from the frontal wall of the early embryo are connate, but are generally notched, the notch indicating where a slit should be. In the lobes of this essentially double lamina the trabeculæ terminate, and they form its pith—just as the pterygo-palatine streak of tissue forms the pith of the maxillary rudiment, *miscalled* "the maxillary process of the first visceral arch," and just as MECKEL's cartilage is the pith of the mandibular arch.

We saw that the second prestomal rod had become inferior, morphologically, to the first poststomal: a still further degradation takes place in the intermaxillary, that is, in its primordial parts; for in the bird the rods coalesce throughout their whole length, whilst the plane of the rods is coincident with that of the cranio-facial axis, of which they, from lack of segmentation, are a mere forward continuation. At this stage (*Struthio*, "A.") these confluent rods (Plate VII. figs. 1–5, *p.n.*) are at their fullest development; afterwards, all that part which is free of the nasal passages anteriorly, gradually shrinks, is very small at the time of hatching, and eventually disappears. The foremost two-thirds of MECKEL'S cartilages undergo the same wasting; but this decadence is not seen in any part of the palatine rod, at least in the Ostrich: in some birds, *e. g.*, the Psittacinæ, the palatines become premorse anteriorly. But this is in the osseous stage, which the prenasal and Meckelian cartilages never attain to, being merely temporary structures.

That part of the premaxillary pith which does continue in the Ostrich, is ossified continuously with the perpendicular ethmoid: this is extremely unlike what obtains in the higher birds, where the vestibular or *sifting* portion of the nasal structures, and the axis of the intermaxillary structures, become wholly segmented from the skull and from that part of the nasal capsule which is supplied with the olfactory filaments, and which gives origin to the palatine pedicel. An exorbitant development of the anterior intermaxillary splints is characteristic of birds, but in *Struthio*, and most of its congeners, it is the vomer which attains to the greatest relative size. There may be four pairs of intermaxillary splints; but in the Ostrich the essentially double vomer (Plate VII. fig. 4, *v.*) is only split at each end—it is an azygous piece; this is the inferior and posterior splint, and is apt to run far backwards into the palatine region, sheathing the coalesced trabecular beam anteriorly, and the rostrum of the basisphenoid behind.

In the Ostrich, as in all birds, the intermaxillaries (Plate VII. *p.x.*) themselves are always symmetrical; but their separateness is extremely transitory; they commence upon the sides of the upper surface of the depressed end of the prenasal rostrum—their proper pith of cartilage. Each piece is composed of a body, from which proceed the nasal (Plate VII. fig. 5, *p.x.*), angular (Plate VII. fig. 3, *p.x.*), and palatine (Plate VII. fig. 4, *p.x.*) processes.

The dentary margin of the body of these bones meets the palatine processes at an acute angle; in the Mammal this space is the anterior half of the "anterior palatine foramen;" it is filled up in the bird on each side by the anterior pointed end of the middle intermaxillary splint. These bones, the "prevomers" (Plate VII. figs. 3 & 4, *p.v.*) have been much misunderstood, being mistaken in the bird for the true maxillaries, and in the Ophidians, Lacertians, and Amphibians for the inferior turbinals.

Already in *Struthio*, "A.," they have almost attained their proper form, and each bone may be described as possessing a body, a nasal, an internal or palatine, an external or zygomatic process, and a pedate proximal process, in relation to the sides of the trabecular rod. In *Struthio camelus* the nasal process is a mere thin and not very broad bridge of bone passing from the proximal to the zygomatic process, on a somewhat higher plane than the body of the bone; thus making the isthmus between the proximal (internal) part and body of the bone to be double.

This bone supplies a good instance of the manner in which a splint bone may be formed by the ossification of an aponeurotic tract quite at right angles to and a great distance from the primary rod to which it belongs. All these splints appear to belong to the *external* category; if so, only the mandible in the Ostrich-tribe has *internal* splints. The coalescence of the axial rods makes this apparent difference.

In *Struthio* the vomer (Plate VII. fig. 4, *v.*) has three prongs anteriorly, and is deeply bilobed behind, passing backwards as an under beam, beyond the middle of the basisphenoidal rostrum in the adult; in *Struthio*, A., one-third of the rostrum is thus underlaid. Certainly the formation of the vomer is at first in the *outer* layer of the perichondrium which invests all that part of the cranio-facial axis lying in front of the antorbital lamina ("pars plana," "middle turbinal"). The "turbinals" have overshadowed intellectually, as they do literally, this matter of the great extent of the primordial part of the intermaxillary apparatus, and the real bearing of its splint-system. Afterwards I will show the fruitfulness of this idea, and how it throws a trail of light along the whole series of "vomers" from their first birth in the Sturgeon to their latest incoming in our own species. The true nature of this splint, the unravelling of the much misunderstood "prevomers," the exact nature of the intermaxillaries proper, and the finding for all these a true embryonic preskeletal basis, is no mean object of ambition.

The rest of the face is the hyoid arch, with its attached thyrohyals (1st branchial arch (Plate VII. fig. 7). The proximal part of the hyoid arch is the "columella" (stapes); it is a mere cylinder of cartilage, which flattens out into an oval disk above, where it serves as an *operculum* to the fenestra ovalis (fenestra of the vestibule), and is branched below, the thin branches not ossifying. Far removed from this part we find the hyoid cornua on a plane with the base of the skull, and altogether small, and coalesced with each other and with a truly basal piece. The cerato-, basi-, and uro-hyals (Plate VII. fig. 7, *c.h.–b.h.–u.h.*) are thus already one piece, which is at present totally unossified. These primordial hyoid horns are an exact imitation of an early state of their serial homologues in the first prestomal (intermaxillary) arch (see HUXLEY'S Elem., p, 138, fig. 57, F′, *rr.*). There is much mystery at present hanging over the relation of the cornua of the hyoid to the proximal pieces. Articulating distally with the basal portion of this hyoid cartilage is a rod of cartilage which has another smaller rod articulated to it above, which latter ends in a point. These are the thyro-hyals (*t.h.* 1 & 2), or rudiments of the first branchial arch; proximally they are free, and curl round behind the occipital cartilage; none of the lingual cartilages possess any splints, as they do in fishes: the lower thyro-hyal is rapidly ossifying in *Struthio*, "A."

Struthio, "B."

The head of the next embryo of *Struthio camelus* measured 2½ inches in length, but although the body of the chick was about the size of that of a pigeon, yet there was nearly a pound weight of unused yolk in the egg.

At this stage the skull has increased to nearly twice the length of that which I have been describing, and with this greatly augmented bulk we also have the incoming of new osseous parts, as well as a great maturation of those already existing, and a commenced deterioration of those *quasi-larval* structures which disappear during the slow, gentle, but real metamorphosis which the parts of the ornithic skull and face undergo.

The angle of the occiput with the basicranial axis (Plate VIII. fig. 1) has greatly lessened, and is not many degrees above a right angle, to which degree of acuteness it never attains even in the adult bird. The base of each hemisphere, anteriorly, is in *Struthio*, A. five lines, or nearly, above the true base of the skull, *i. e.* the lower edge of the basisphenoidal rostrum; in *Struthio*, B. it is seven lines, and in the adult twenty-one, or an inch and three-quarters, the rostrum at that part being seven lines in depth. But the brain at this part lies on the gently *convex* surface of the orbitosphenoids; the anterior sphenoid is thus altogether lifted up above the actual basal line of the skull, the whole depth of the basisphenoid below and just in front of the optic foramina being in the adult a full inch. To the student of the mammalian skull all these details will appear strange enough; but the bird's skull is a curious problem, and he who shall explain it will have done much towards producing a harmony of all vertebrate crania.

The cartilaginous investing mass in *Struthio*, B., has on each side grown nearer to the mid line; the notochord has thus thus become pinched into a thin vertical plate; the basioccipital and the exoccipital (Plate VIII. fig. 2, *b.o.e.o.*) also, have increased both relatively and really, the cartilage within their laminæ being much metamorphosed. In the superoccipital region a large, irregularly hexagonal plate of bone has appeared, reaching above to the converged parietals, and below already bounding the "foramen magnum" (Plates VIII. fig. 4, *s.o.*). I have not been able to see this superoccipital element on its first appearance in the "Struthionidæ," but the only genus in which I have found it as an originally azygous piece is *Turdus* (the Thrushes); even in *Passer*, *Erythacus*, and *Corvus*—good representatives of three great, and eminently typical families—there are two superoccipitals at first. And it may be also noted that this element is, relatively, exorbitantly large in the Ostrich-tribe.

The cartilage investing the auditory capsule has greatly increased in thickness, and the prootic and opisthotic (Plate VIII. fig. 4, *op.*) bones have just appeared; the latter may be seen externally (its outer lamina) outside the base of the "posterior vertical canal."

The basitemporals have coalesced (Plate VIII. fig. 2, *b.t.*) and form a narrow band reaching across beneath the skull from one internal carotid opening (*i.c.*) to the other; but they have also entirely coalesced with the terminal end of the true basisphenoid, so that already their exact limits cannot be seen; yet it is evident from other members of this group of birds that this temporal belt is partly formed by the basisphenoid in the mid line. Not only has the bony matter spread far along the great anterior pterygoid processes, but has also sent out two more (posterior) wings, the ossific matter of which is creeping into the anterior part of the broad investing mass (Plate VIII. fig. 2, *p.r.p.*).

The "rostrum" (Plate VIII. figs. 1 & 2, *r.b.s.*) has greatly increased in size and has become relatively longer, reaching to the extreme limits of the alæ nasi and external nasal passages. There is still a thick spheno-occipital synchondrosis, and an oval remnant of the pituitary fontanelle (Plate VIII. fig. 2, *p.t.s.*). Two oblong jagged centres have appeared in the alisphenoidal cartilage, one above and the other below (Plate VIII. fig. 1, *a.s.*); they are nearly equal in size, the upper being the longest; there are two nearly equal bones formed in the front in *Passer domesticus*; and in *Nisus vulgaris* there is a small ossicle in front of the main piece. The anterior sphenoid (Plate VIII. fig. 1, *o.s.p.s.*) is still wholly unossified; it is, as it were, altogether hindered in its growth and development by the excessive size of the territories bounding it before and behind: lateness of ossification is a very constant concomitant of cramped development, just as an overshadowed tree is slow in its leafing.

The ethmoid has commenced to ossify both in its upper and perpendicular portions (Plate VIII. figs. 1 & 3, *eth. p.e.*); but I will defer a description of these until I come to describe a somewhat later stage (*Struthio*, C.).

The cranial and nasal splint bones (*f.p.n.*) have increased relatively, as well as really, and the fronto-parietal fontanelle (Plate VIII. fig. 3, *fo.*) is very small; the frontals and parietals are coming extensively into contact, and are forming the coronal and sagittal sutures; the middle third of the lambdoidal suture (Plate VIII. fig. 4) is also complete.

The nasals and lacrymals (*n.l.*) are becoming dense through the more perfect ossification of the fibrous lamina in which they are developed. The same may be said of all the splint bones seen in the facial parts of the skull and in the mandible. The pterygoid (*p.g.*) has become more nearly like that of the adult bird, and the palatine (*pa.*) has lost the sharp point at its anterior end. The broad proximal, the distal, and metapterygoid portions of the "os quadratum" (*q.*) (incus) are still unossified, like the ends of the anterior pterygoid processes; and the base and shaft of the "columella" (*st.*) have become bony. But the *malleal* part of the mandible is still soft, even its articular persistent end (Plate VIII. figs. 1 & 5, *ar.*). The whole of the lingual cartilages have merely grown, but have not altered their condition, as to ossification, from what we saw in *Struthio*, "A." (Plate VIII. fig. 6).

Struthio, "C."

In *Struthio*, C. all these processes have advanced a step or two further, although no new bony centre has appeared. The upper fontanelle has almost disappeared. The superoccipital is spreading laterally, the exoccipitals (Plate VIII. fig. 8, *e.o.*) have acquired an elegant fan-shaped form behind; the notochord (Plate VIII. fig. 10, *n.c.*) has its anterior two-thirds enclosed in bone (basioccipital), from the fusion of the two laminæ. The two laminæ of the basisphenoid (Plate VIII. fig. 10, *b.s.*) have coalesced, and the clinoid regions are becoming bony; the alisphenoid (*a.s.*) is entirely ossified. The posterior part of the anterior vertical canal (Plate VIII. fig. 10, *a.s.c.*) is enclosed in the superoccipital, and the ampulla is now embodied in the "prootic" (*pro.*), which is bilobate, and which commenced on the supero-anterior thick edge of the auditory capsule: beginning at a selvedge, it was most probably single from the first. The opisthotic (Plate VIII. figs. 8 & 10, *op.*) is five or six times the size we saw it in *Struthio*, B.; its outer lamina (fig. 8) is an inverted crescent; its inner (fig. 10) is semicircular; they are quite distinct. A very large mass of occipital and auditory cartilage (Plate VIII. figs. 8, 9, 10) is still in a soft state, as is all the rest of the cranio-facial axis, except the ethmoid. The middle or perpendicular ethmoid (Plate VIII. fig. 10, *p.e.*) has an ossification which is roundish, and is nearly 4 lines in diameter; its two laminæ (right and left) have coalesced by a small internal isthmus (Plate X. fig. 1, *p.e.*); and the edges are creeping in all directions *on* and *into* the cartilaginous mass.

It may be remarked here that this mode of *diaphysial* ossification,—viz. by two external laminæ, where there are two free surfaces to the cartilage, by one where there is only one, by a bilobate ossicle when the bone begins on a selvedge, and by a ring in cylindrical rods—is never departed from (as far as I have seen) in the oviparous vertebrata.

In by far the greater number of instances the process is the same amongst the Mammalia; but in the Fish (*Teleostei*) the retention of a pith of unchanged and constantly proliferating cartilage is the rule. This is not a gathering together into definite bone-plots of the tiny ossicles which are scattered broadcast over the cartilage in the Plagiostomes, for their bone-grains are intercellular. The thin bony sheath (but for sectional views) might easily be mistaken either in the adult fish, or in the embryos of the higher group, for a splint bone, especially as it often appears in cylindrical bones on one side at first, that side being the freest and most exposed. It must also be held in mind that there is a stage in which the new bony matter has not as yet touched the cartilage-cells, and that this is a persistent condition in certain delicate minute fish, e. g. *Gobius minutus*. Returning to the ethmoid of *Struthio*, C., we find a condition which is apparently unique; for the ethnoidal alæ which turn over to form the feeble cribriform plate are not ossified separately as in most of the typical birds, the middle plate in them being entirely completed by the vertical piece, but a bone begins at the top of the broad surface, oval in form, and having only this upper lamina (Plate VIII. figs. 3 & 10, *eth.*). The upper part of the prefrontals, at least, are thus *connate*; but the "pars plana" generally has its own centre, or centres, even in the Struthionidæ.

The cartilage between these two ethmoidal bones in *Struthio*, "C." is only a line deep, and coalescence soon takes place. No other bone appears in the cranio-facial axis; for these two azygous bones, after they anchylose, spread forwards through the whole of the septum nasi, which in this abnormal group is not differentiated from the middle ethmoid. The alæ of the septum, or roots of the great inferior turbinal cartilages, are ossified continuously in the same way, and as a roof to the continuous vertical plate; but the mass of these cartilaginous folds continues soft in the adult. Seen from within, the "upper," "middle," "inferior," and alinasal turbinals form one connected, continuous series of swelling masses (Plate VIII. fig. 7); but the representative of the upper turbinal and its cribriform plate in the Mammal is here a mere descending wing (Plate X. fig. 1, *al.e.*), only folding upon itself where it passes insensibly into the roots of the inferior turbinal; and the olfactory lobe lies *between* it and the middle plate (Plate X. fig. 1, $_1$), in that chink which is so copiously bridged over, and thus converted into a vertical row of holes in the Mammal. The spaces seen on the side of the upper turbinal fold behind (Plate VIII. fig. 1, *p.e.*), where it passes into the "pars plana," are not for olfactory filaments, but depend upon a certain unfinished condition of the cartilaginous lamella, and are quite inside, and even behind that part of the olfactory crus which gives off the filaments. A fissure lower down (Plate VIII. fig. 1, *al.e.pp.*) partly divides the upper turbinal lamella from the large but very *simple* "pars plana," but above that there is a broad continuous connecting plate. Below, at its external angle, the pars plana is connected with the outstanding, foot-shaped, lower end of the inferior turbinal (Plate X. fig. 1, *a.i.t.*) by a narrow isthmus; so that there are three antorbital plates, or rather regions—an upper or inner, a middle or lower, and an outer and somewhat anterior lobe; these belong respectively to the upper, middle, and lower turbinals.

The only fold or outgrowth which can safely be said to belong to the middle turbinal is near the base of the pars plana (Plate VIII. fig. 11, *m.t.b.*); it is triangular, horizontal, and runs outwards and forwards, lying between the largest posterior part of the inferior turbinal and the proximal plate of the prevomer. The most complex part of the inferior turbinal (Plate X. fig. 3, *i.t.*) is the fullest or hinder part; and although much less complex than that of the Cassowary, or even than that of the Emu, it is yet greatly in advance of the same part in the *Rhea*, the Tinamou, or the typical bird. The septal ala (Plate X. fig. 3, *al.s.*) passes outwards, downwards, and then inwards, walling in the whole nasal labyrinth, save for the chink between the free edge of the alæ and the base of the septum (Plate X. fig. 3). Where the aliseptal cartilage begins to turn downwards it sends off an outgrowth, which is directly vertical behind, and afterwards turns inwards; at this anterior part it splits into two lamellæ, which curl upwards, each being about a semicircle (Plate X. fig. 3, *i.t.*). But posteriorly these secondary lamellæ are divided again; and of these tertiary folds, the nearest but one to the septum forms more than a complete coil (Plate X. fig. 3, *i.t.*). Below these lamellæ another has been given off from the outer (primary) wall (Plate X. figs. 3, 4, 5, *n.t.*), and when this reaches the alinasal region it becomes as complex as the front part of the inferior turbinal; this is the "alinasal turbinal." The septum, as soon as we pass in front of the olfactory bulbs, is very thick at top; it then becomes thin, and thickens into a strong (trabecular) beam; this beam being underlaid by the "rostrum," and this again by the vomer (Plate X.

figs. 3, 4, 5, *s.n. r.b.s. v.*). Further forwards, the septum gently narrows to the middle, and then thickens again towards the base, the sectional view of which is always bulbous (Plate X. fig. 5). The alæ nasi grow forwards beyond their *axial* attachment; between them runs the evanescent premaxillary axis, which is flattened from above downwards (Plate X. fig. 6). There is no such outgrowing of the base of the septum as is to be seen in the embryo Ox, in the Crocodile, and in the Frog; yet such an inferior expansion is to be seen in many birds, especially the Raptores. In the Turtle (*Chelone mydas*) the alæ nasi and the base of the septum become confluent at one point.

Rhea.

My illustrations of the development of the skull of the *Rhea* will be from a comparison of the adult skull with that of the ripe *pullus.* I have already given figures of the adult *Rhea americana*, Zool. Trans. vol. v. pl. 42; and there are several notices of its structure in that paper, more especially as compared with that of the Syrrhaptes and the Tinamou. The ripe chicks of the Rhea from the Gardens of the Zoological Society were of a *mixed* kind; the *sire* being the subspecies (?) called *R. macrorhyncha* by Dr. SCLATER (Zool. Trans. vol. iv. pt. 8. pl. 69, & fig. 2. p. 356; & P.Z.S. 1860, p. 207), whilst the *dam* was the ordinary *R. americana.* In some respects the *Rhea* comes much nearer the ordinary land birds, e. g. *Otis*, *Gallus*, than the African Ostrich; in others it is much more aberrant from the ornithic type. It is also the best bird in the Class for illustrating the structure of the Fish, and the lower kinds of Reptilia—the Amphibians, Ophidians, and Lacertians. Notwithstanding the large size of these *pulli*, the cartilage-bones have not all appeared, but the membrane-bones have attained to a degree of development almost equal to that which is found in an ordinary adult Lacertian. The condition, moreover, of the primordial (*larval*) skull is such as will have to undergo great changes of relative proportion, and of subsequent resorption in certain tracts, before it reaches its adult condition.

A chink in the upper aspect of the oval basioccipital shows a feeble remnant of the notochord in its axis (Plate IX. fig. 1, *b.o.*.); the bone itself is insulated by cartilage. The exoccipitals are large, hourglass-shaped within (Plate IX. fig. 1, *e.o.*), and trilobate at the external and outer margin (Plate IX. fig. 6, *e.o.*); a notch above, near the crescentic venous groove, shows that a large peninsula of this bone (above) belongs to the opisthotic (*op.*), which is still distinct within (Plate X. fig. 7, *op.*): this is exactly like what we see in the ripe embryo of the Crocodile. The occipital condyle is bilobate transversely (Plate IX. fig. 1), as is very common in birds having a smack of the reptile in them; it is still cartilaginous, but the ex- and basi-occipitals are creeping into it at its sides and in front. The superoccipital (Plate IX. fig. 6, *s.o.*) shows no trace of suture down its middle (although assuredly it did once exist, if *analogy* is of any value); it is a large, elegant, six-sided, winged bone, angular above, crescentic below, grooved and perforated for veins submarginally, and has the upper part of its sides convex, the lower concave. This bone has a large margin of cartilage on each side of it; it has, however, reached the foramen magnum below, and the sagittal suture between the parietals above. It has embraced three-fourths of the anterior semicircular canal within (Plate X. fig. 7, *a.s.c.*); thus anticipating the epiotic in its function, and, as it were, causing it to be both late and small: this is extremely common, and in by far the larger proportion of birds the epiotic is prevented from appearing by this vicarious overgrowth of the superoccipital; this is well seen also in the Chelonians.

The "occipito-sphenoidal synchondrosis" (Plate X. fig. 7) is nearly a line in fore-and-aft extent, and a notable margin of cartilage divides the whole body of the basisphenoid from its neighbour-bones laterally, *e. g.* the alisphenoid and the prootic (Plate X. fig. 7). The two lamellæ of the basisphenoid are completely welded together, and the two lateral lamellæ (the basitemporals) have also coalesced *with the sides* of the basisphenoid below (Plate X. fig. 7, *bt.*). Two small passages, connected by a groove, feebly remind us of the once large pituitary space; behind these the basisphenoid can be seen growing towards the basioccipital, the basitemporals being *lateral*, as in the Mammalia (Plate IX. fig. 4). That mass of cartilage which takes the place of RATHKE'S "middle trabecula" (the posterior clinoid bridge) (Plate IX. fig. 1, *p.cl.*) runs continuously across the floor of the skull into the tract which at present separates the alisphenoid from the prootic. This clinoid bridge is filially related to the tissue which formed the most projecting angle of the skull-base in the "cranial flexure" of the early embryo. In front of the "infundibulum" the ossific matter has reached the common optic foramen (Plate IX. fig. 2, & Plate X. fig. 7, *bs.*); so that there is a large compressed prepituitary portion already developed to the basisphenoid; afterwards it will have grown forward enough to meet and coalesce with the vertical ethmoid (*p.e.*), although they are at present 4 lines apart. The acquisition of the basitemporals gives the basisphenoid a bilobate form behind and below (Plate IX. fig. 4); above, the bone is split beneath the clinoid bridge (Plate IX. fig. 1), and the fissure is the remnant of the space in which the extreme point of the notochord neared the infundibulum: it is much larger in Reptiles, and being in them deficient of cartilage, forms the "posterior basicranial fontanelle" of RATHKE. The, at present, rather slender "rostrum" runs forwards to the middle of the alæ nasi (Plate IX. fig. 2, & Plate X. fig. 7, *r.bs.*); it is relatively somewhat shorter in the adult; it is entirely ossified. The alisphenoids (Plates IX. & X. *a.s.*) are at this stage composed only of one piece; but the ossific matter has scarcely reached the great trigeminal nerve (5), and overarches only the ophthalmic (5, *a*); the anterior margin is also soft, and so is part of the supero-external angle. Only part, however; for here is developed the true (*ichthyic*) "postfrontal" (Plate X. fig. 8, *pf.*); it is somewhat like the blade of a hatchet, and is a line and a half across. It is best seen in the Rhea of any bird I am acquainted with, although it turns up in the Emu and the Tinamou (as we shall see), in the typical "Raptores," e. g. *Nisus vulgaris*, and in the nocturnal species also, *e. g.* the Barn-Owl (*Strix flammea*). This bone is not the homologue of the so-called postfrontal of the Reptile, which is a mere postorbital scale, and a reappearance (in a feebler form) of that postero-lateral roof-scale of the Sturgeon which Professor HUXLEY, by a curious twin-mistake, has at once compared to the "pterotic" of the Fish and to the squamosal of the air-breathing Vertebrata (see 'Principles of Comp. Anat.' p. 205. fig. 82, F.).

The outer anchylosed part of the opisthotic is oblong; the inner free lamina is wedge-shaped; only a fissure separates it from the exoccipital, but a clear margin of cartilage insulates it from the prootic (Plate X. fig. 7, *op. pro. e.o.*). This latter piece is at present entirely *within* the skull (see fig. 2 of Plate IX., showing its absence on the outside), its commencement being close to the internal meatus, as in birds generally, and not over the ampulla of the anterior canal, as in *Struthio* (Plate VIII. fig. 10, *pro.*). In the Sheep, when the fœtal head is 2 inches 9 lines in length, the relatively small prootic has commenced by two ossific patches at the same part, as in the African Ostrich. I mention this to show how *ornithically* aberrant the Great Ostrich is in this respect. In the osseous Fish the prootic, of necessity, is developed from an *outer* lamella, although the bony matter creeps round into the skull behind the trigeminal nerve, and finds all the good solid cartilage there is, especially towards the base; it thus may be seen skinning over the periotic basicranial bridge (see HUXLEY, *op. cit.* p. 167, fig. 68, *p.r.o.*).

Laterally the whole of the periotic cartilage is still soft in the ripe pullus of the Rhea (*supra*), as is also the thick edge of the paroccipital wing (Plate IX. fig. 2, *e.o.*), which is continuous with it, but within (Plate X. fig. 7, *pro.*) the prootic walls in much of the cranium; it is roughly hourglass-shaped, and has the multiperforate fossa for the seventh nerve exactly in its centre.

The epiotic (mastoid) has not yet made its appearance; there is some room left for it, however, in the cartilage which hides the junction of the anterior and posterior canals, in that which lines the "lateral cerebellar fossa," and outside the crown of the great "anterior semicircular canal" (Plate IX. fig. 2, & Plate X. fig. 7).

The anterior sphenoid (*o.s. p.s.*) is as yet unossified; its region is small, as in most birds, and its alæ (orbitosphenoids) are the mere outturned edges of its thickened top (Plate IX. fig. 1, *o.s.*). The vertical part is rather thin below, and is bounded in front by the interorbital fenestra, and behind by the common optic passage. A large fissure, filled up by a remnant of the early membranous skull, separates the anterior sphenoid from the great ala on each side; it is a temporary orbito-alisphenoidal fontanelle (Plate X. fig. 8.), the merest trace of which can be seen just above the optic passage in the adult.

A large pear-shaped fenestra has been formed in front of the presphenoid (Plate IX. fig. 2, *i.o.s.*) as large as that cartilage; the deficiency of cartilage here depends upon the room required by the large eyes, which nearly touch each other, and by a growth of the septum too rapid for the proliferation of the cartilage-cells. The band of cartilage above this fenestra is about a line deep, most of it being ossified by the vertical ethmoid; in the adult it is nearly—in old age, perhaps, quite—filled in by periosteal layers of bone. The vertical ethmoid (Plate X. fig. 7, *p.e.*) is already a large plate of bone; it does not quite reach the fenestra behind; has not reached the trabecular region below, but above it has become anchylosed to a great extent to the broad upper bony piece—the connate upper prefrontals (Plate IX. fig. 1, *eth.*). This latter bone is pear-shaped on its upper, partly exposed aspect (Plate IX. fig. 5, *eth.*), the crista galli being nearly hardened by it at its narrow hinder end; its broad front portion has extended nearly as far as it will extend, into the root of each upper turbinal (Plate IX. fig. 1). Relatively, in the adult, it reaches one-third further forwards; then the septal region is cartilaginous for a slight extent (3 lines), and then an equal-sized tract of bone ends it in front. The coalesced ethmoid bones terminate in a nearly straight line in front; this truncate end leaning backwards below, at which part the rest of the septum is a styliform cartilage an inch in length. Between this lower and the partly ossified upper bar, there is a large notch (Zoological Transactions, vol. v. plate 42, fig. 4, *eth. s.n.*). We here catch the first glimpse of the important septum nasi of the typical bird. The whole septal region is relatively much smaller in the adult than in the young Rhea. In the young, the vertical ethmoid is a hatchet-shaped ossicle, thickest where the "pars plana" approaches it; in the old bird an oval fenestra, 6 lines by 4, has been caused by the absorption of the bone above the relatively lessened pars plana, and between the termination of the olfactory crura (see *op. cit.* plate 42, fig. 4, *m.s.*).

I see no turbinal outgrowths on the down- and in-turned upper lamella (Plate X. fig. 9, *al.e*), but external to the confluence of the huge inferior turbinal with the pars plana there is, inside its elegantly plicate external part (Plate X. fig. 11, *p.p*), an obliquely vertical oblong outgrowth, which in a sinuous manner turns first inwards and then outwards (Plate X. fig. 10, *m.t.b*). Both margins of the pars plana are free, but above it runs insensibly into the rudiment of the cribriform plate (aliethmoid), and in front and below it is to some degree confluent with the funnel-shaped end of the large inferior turbinal (Plate X. fig. 11, *i.t.b.*). This latter cartilage has its root in the septal region, all along from the upper turbinal to the commencement of the alæ nasi (Plates IX. & X. *al.s.*). The simple aliethmoidal lamella turns inwards, where it receives the olfactory filaments and protects the bulb (Plate IX. fig. 2, & Plate X. fig. 9, *al.e.*); as soon as this cartilage expands again it has become the root of the inferior (anterior) turbinal. This ala of the septum stretches out some distance, then curls round a little, then splits into two lamellæ (Plate X. figs. 14, 15), the outer of which forms the semicylindrical wall of this part of the nasal labyrinth; the inner lamella (*i.t.b.*) turns abruptly inwards, coiling itself into a most beautiful scroll, with three complete turns of the spire. This inferior turbinal scroll is half an inch in length in the ripe pullus; the scroll is, at its middle, 2 lines in diameter; a shallow fossa passing from above, rather suddenly backwards, shows from the outside where the egg-shaped alinasal fold begins (Plate IX. figs. 1–3, *al.n.*). This lamina, continuous with the last, is not simple, but the secondary plait which arises within it, and which turns inwards, bifurcates, one plait half the width of the other, turning upwards and outwards, the other downwards and outwards (Plate X. fig. 16). Inside this double lamella (the alinasal turbinal) there is a thick cushion of dense fibrous tissue. The only part of these cartilaginous folds which ossifies is the pars plana; there is one centre for the inner part which walls in the end of the inferior turbinal scroll, and which runs upwards towards the olfactory crus; and another for the plaited part which sends inwards the middle turbinal outgrowth (Zoological Transactions, vol. v. plate 42, fig. 4, *ao.* 1, *ao.* 2). Already the prenasal rostrum is diminishing in size, afterwards it will vanish, and with it a goodly territory of the septum between the alæ nasi; thus two cartilaginous, and one actually ossified tract, disappear by the time the bird is full-grown. Mere connective fibre is left in these absorbed regions. Three tracts of unossified cartilage are seen in a section of the ethmoid in the ripe young; the upper is the core of the upper bone, the middle is above the junction of the two vertical lamellæ, and below the coalescence of the upper and lower bone; the lowest tract is between the vertical lamellæ, and is continuous with the unchanged trabecular region (Plate X. fig. 13). I have already shown that the prenasal rod (*pn.*), formed by the coalescence of the anterior horns of the trabeculæ, is really the proper axis of the intermaxillary apparatus; the primordial part of the palatine arch behaves differently. As in *Struthio*, the palatines and pterygoids (Plate IX. figs. 1, 2 & 4, *pa.pg.*) ossify whilst the tissue is in a simply cellular condition; the pterygoids are like those of the Ostrich-tribe, but the palatines show scarcely any of the anterior bar, and thus differ very much not only from ordinary birds, but also from the Great Ostrich. Indeed the whole bar is almost divided obliquely from end to end to form the pterygoid and palatine, the former being broad behind and sharp in front, and the latter narrow and broad in the contrary direction; the inner edge of the broad deeply-toothed anterior end of the palatine is the suspensory part of this arcade, the axis of the pterygo-palatine apparatus*. The triradiate, massive, quadrate cartilage (Plate IX. *q.*) is still unossified at the end of its metapterygoid process, and at the upper and lower articular surfaces; the former is a continuous oblong condyle, as in all the congeners of this genus. The "articulare" (Plate IX. figs 2 & 3, *ar.*) has begun to form in the thick *malleal* head of MECKEL's cartilage; its first lamella appears in the flat posterior face, which ends inwards in the clubbed internal angular (manubrial) process; all the rest of the primordial part of the mandible is still cartilaginous (Plate IX. fig. 2, *mk.*), anteriorly it has begun to shrink. The main part of the auditory columella (Plate IX. fig. 3, *st.*) (stapes) has ossified, the cartilaginous part is triple; one flat bar in a line with the bony rod, a long terete branch, running forwards at right angles to the stem, and a smaller similar rod going directly backwards. This is the detached suspensory part of the hyoid arch; the disjoined rami and base are, together, elegantly arrow-shaped (Plate IX. fig. 7, *c.h.b.h.*), for each flat cerato-hyal cartilage has joined its fellow at the mid line, forming a point anteriorly, whilst each ramus passes backwards free and pointed. The basihyal is very pointed in front where it fits into the acute angle formed by the meeting of the flat cornua; it has no uro-hyal prolongation, the thyro-hyals (*th.* 1, *th.* 2) (1st branchials) articulating on each side of its somewhat broadened end. The third poststomal is, as usual, composed of two rods on each side; ossification has far advanced in the larger proximal rod. The upper thyro-hyals, the basi-, and the cerato-hyals are not at present in the least ossified.

---

* Only the *pier* of the paláto-pterygoid arch is ever developed in the Vertebrata generally; there is no segmented descending rod.

Having despatched the primordial parts of the Rhea's skull and face, I turn to the *opercular* or splint-bone series. Most of these have already assumed very much of their persistent form, but they are entirely unanchylosed; so they thus present us with an extremely valuable series of objects for comparison with other vertebrates.

The upper, marginal, and orbital regions of the frontals (Plate IX. figs. 3–6, *f.*) are well formed, and the bone is acquiring a considerable thickness; the same may be said of the parietals (*p.*); only a trace of the two sagittal fontanelles can be seen (Plate IX. fig. 5). The lacrymals and nasals (lateral and upper ethmoidal splints) are completely formed (*l.n.*), the latter having no descending process (Plate IX. fig. 5, *n.*), thus differing from *Struthio*, and the former having a large fenestra in its antorbital plate (Plate IX. fig. 3, *l.*). Ostrich-like, the nasal processes of the intermaxillaries are completely fused (Plate IX. fig. 5, *px.*); they end in front of the broad upper ethmoidal bone, which condition is not lost in the adult. Round that bone, the blunt styles formed by the posterior part of the nasals creep for some distance on to the narrow, wedge-like ends of the frontals (Plate IX. fig. 5). The large, extremely thin and splintery palatine processes of the intermaxillaries (Plate IX. fig. 4, *px.*) are very remarkable, and they are separated by a very clearly cut fissure from the marginal part; into this fissure, behind, where it widens, the pointed wedge-like end of the prevomer (Plate IX. fig. 4, *pv.*) fits, thus obliterating the "anterior palatine foramen."

The prevomers have their largest relative development in the Rhea, and their smallest in the "Gallinæ," "Tetraoninæ," "Pteroclinæ," and "Hemipodiinæ" (compare the figures in plates 34–36 with *pv.* in plate 42 of Zoological Transactions, vol. v.).

The very perfect development of the ascending process (Plate IX. figs. 3 & 5, and Plate X. fig. 14) makes this bone in the Rhea very valuable for comparison with that of the Ophidian; and although the nasal gland is not enclosed between the vomer and prevomer as in the snake, yet its duct so passes down outside the great inferior turbinal as to pour the secretion out at the identical place in which it is discharged in that reptile (Plate IX. fig. 3, *d.n.g.*). Moreover, the root of the ascending process of the Rhea's prevomer is to be seen ascending *over* the edge of the deeply bifurcate vomer (Plate X. fig. 14, *v.*), which is almost a double bone. This submesial portion of the prevomer is in reality the *proximal* portion, which has its immediate relation to the intermaxillary axis, as the middle splint; all the rest of the bone, which has spread out to such an exorbitant size, receives its explanation in the fact that in the Bird this splint takes up the place which should for the most part be filled by the maxillary. Serially, the prevomer is the homologue of the "interpalatine." A large irregular fenestra is formed in this bone in the adult bird; it is curiously scooped below (Zoological Transactions, vol. v. plate 42, *pv.*), and a notch has appeared separating the palatine from the proximal process; the palatine and zygomatic processes of the prevomer are not far from parallel, and are nearly of the same length (Plate IX. fig. 4). The proximal (submesial) part of the prevomer of the Rhea is much wider than that of the Ostrich, and is less distinctly marked off from the body of the bone. To sum up the regions of this huge bone—a bone so strongly limited as to its occurrence in a separate condition in the classes and orders of the Vertebrata, but constant and attaining its highest autogenous condition in birds—we have a body, a premaxillary, an ascending, a proximal, a palatine, and a zygomatic process.

The vomer of the Rhea (Plate IX. fig. 4, *v*) is exceedingly instructive, being very large, and having its two symmetrical halves united merely by an isthmus at its middle, only one-fourth the length of the bone, so that it has but narrowly escaped being double —a condition not really wanting in the bird-class, *e. g.* in *Numida meleagris* and *Musicapa grisola.*

The vomer of the Rhea is a very close counterpart of that of the Chelonians, a group peculiar amongst reptiles in having this bone azygous; for the middle part or septum of the "middle nares" is high, compressed, and keeled below, whilst the hinder part is on a higher plane than the front portion. The front part is divided by a deep, clean, oblong notch, and the rami, grooved below, lie on the enormous palatine plates of the intermaxillaries; in the Chelonian the front part is unsplit, and is affixed by a transverse suture to the short palatine portion of the intermaxillaries. The higher placed, outspread, posterior portion of the vomer in both the Tortoise and the Rhea, articulates with both the palatines and the pterygoids; the inner part of the maxillary of the Chelonian, in relation to the vomer, just takes the place of the prevomer of the bird.

Again, in this genus there is no maxillary splint-bone; this part of the face is subject to extreme reverses of development even when present, but its absence in perhaps more than *ninety-five per cent.* of the ornithic genera, appears to have been hitherto unexpected and unlooked for.

Both to Professor Huxley and myself the prevomer of the bird seemed to be a very awkwardly fitting representative of the maxilla of the other classes, but it was not until a rudiment of the true maxilla turned up to me in an unripe Emu-chick that the real state of the case was understood.

The anterior and posterior external splints of the pterygo-palatine arcade, viz. the jugal and quadrato-jugal (Plate IX. figs. 3–5, *j.qj.*) are very feeble, as usual, in the Rhea; the latter is extremely short and passes within the jugal, only appearing outside, close to its articulation with the quadrate bone. These outwardly-drawn splints are persistently distinct (see Zool. Trans. vol. v. plate 42, figs. 1, 2, & 4, *j.qj.*).

The proximal or suspensorial splint of the mandibular arch is not long a free bone, but soon coalesces with the sides of the skull proper and auditory capsule; it is the squamosal (Plate IX. figs. 3–6, *sq.*), and is very large and *batrachoid* in this bird, as in the other Ostriches; and, as in the rest of this group, although not in other birds, it is excluded from the cranial cavity, of which it only forms at any time a vicarious part.

It is well ossified in the mature chick of the Rhea, and clamps the quadrate cartilage very strongly; it also helps the prootic capsule to carry the single condyle of the os quadratum, whilst the hinder part of its lower margin forms a strong eave to the tympanic chamber, but does not carry the fibro-cartilaginous tympanic ring; this part is untouched when the squamosal is slipped off in the macerated skull (Plate IX. fig. 2).

The free or Meckelian part of the mandible has its usual splints; viz., three external, the dentary, surangular, and angular (Plate IX. fig. 3, *d.a.sa.*); and two internal, the splenial and the coronoid; they are well developed at the time of hatching, but are free. In the old bird the dentary keeps its distinctness, and the splenial does not make haste to coalesce with its neighbours.

There are no splints to the enfeebled hyoid arch, and it is instructive to see how suddenly the development of the second and third poststomal arches is stopped, whilst the succeeding ones exist only for a few days, even as simple cellular tissue. The descending plate, which grows from the investing mass to form the piers of both the mandibular and hyoid arches, is in all fishes subdivided so as to form an immense proximal piece for the attachment of the segmented hyoid crus. But directly we come to the air-breathing groups, with open nostrils and a tympanic cavity, then we see this mass giving most of its proliferating tissue to the formation of the mandibular pier, the proximal part of the hyoid arch being converted into the auditory columella or stapes. In mammals, where the hyoid arch is not unfrequently attached to the skull, this is attained, not by a resumption of the proper suspensorium, but by a direct downgrowth from the epiotic region of the auditory cartilage.

Dromæus, "A."

My youngest specimen of the Emu is an embryo one week short of the full period of incubation; it is of the species *Dromæus irroratus* of SCLATER and BARTLETT.

I have been very fortunate in obtaining five different stages of development of the skull in the genus *Dromæus*; some belonging to *D. irroratus*, and others to *D. novæ-hollandiæ*. Moreover the study of this genus is very important, as, like the Dinornis, it belongs to the Casuarine group, in which the mammalian characters become most unmistakeable. Already in *Dromæus*, A., the ossific process is far advanced, and in some respects further than in the young pulli of the Rhea, which had been incubated eight weeks, or one longer than in this instance. The basioccipital (Plate XI. fig. 2, *b.o.*) is much larger than in the Rhea, and is less evenly oblong, swelling out between the entrance of the internal carotids (Plate XI. fig. 2, *i.c.*), and then wedging itself in between the ovoidal basitemporals (*bt.*), and applying itself by a narrow but transverse surface to the end of the basisphenoid, this synchondrosis being well seen below. A narrow band of cartilage separates the last bone from its arches, the exoccipitals (*e.o.*), and they have already reached their huge key-stone, the superoccipital (*s.o.*). Behind, the opisthotic forms an upper lobe of the exoccipital (Plate XI. fig. 4, *op.*) united by a broad isthmus; within it is free (Plate XI. fig. 7, *op*), as in the Crocodile and the Rhea. The condyloid foramina, and those for the vagus (8, 9), are quite surrounded by the bony matter of the exoccipitals; the paroccipital ala is still soft (*e.o.*) at its thick margin. The large lozenge-shaped superoccipital (*s.o.*) forms nearly a right angle by the meeting anteriorly of its parietal margins; these edges are not straight, but convex at the ends and concave at the middle. More than a fourth of the occipital foramen is formed above by this bone (Plate XI. fig. 4, *s.o.*). The great sinus-passage opens out 4 lines from its fellow in a deep groove, beyond which the bone is fast extending (Plate XI. fig. 2, *s.c.*); the whole breadth of this (once double) bone is 6½ lines, its height 6 lines. The basisphenoid is largely ossified, and the small basitemporals, pushed from each other by the azygous piece, having coalesced with its sides behind (Plate XI. figs. 2 & 7, *b.s.b.t.*), they form the hindermost of three pairs of wings, now growing out of the thick part of the great basisphenoid. These *lingular* elements are 2 lines long by 1½ line in breadth; they are grooved on their upper surface by the internal carotid (*i.c.*). The middle pair of wings grow directly out of the body of the basisphenoid; they are the thick, broad "posterior pterygoid processes" (*pr.p.*); they are deeply scooped from behind forwards to give capacity to the ear-drum. Between these two pairs of wings there is a shallow groove, the badly defined "Eustachian tube" (Plate XI. fig. 7, *Eu.*); and between the posterior and anterior pterygoid processes (*a.p.*) there is a notch, a groove, and a foramen. The latter processes (anterior pterygoid) have their usual large size, and are turned forwards as well as outwards; between these spurs there are a few vascular passages where the membranous pituitary space once existed. The rostrum (*r.b.s.*) fails of its gigantic size in this genus, but at this early stage it is ¾ inch long and a line in thickness at its root; it reaches nearly to the alæ nasi. The deep prepituitary portion of the basisphenoid is already far advanced; and the alisphenoids are almost completely ossified (Plate XI. fig. 1, *b.s.a.s.*); within, a nearly horizontal ridge divides the upper third from the lower two-thirds, both of these spaces being concave; the high postero-superior angle entirely shuts out the squamosal from the cranial cavity; the postfrontal process is still soft (Plate XI. fig. 1, *pf.*). We saw that the outer lamina of the opisthotic had coalesced below with the upper edge of the exoccipital; within, the fan-shaped inner plate has all but coalesced with the exoccipital, whilst a clear band of cartilage divides it from the prootic. This *reptilian* disposal of the "otic" centres prevails throughout the Bird-class, and is in perfect harmony with numberless other erpetic characters. A large space of cartilage separates the prootic above from the epiotic process of the superoccipital (Plate XI. fig. 4); in this the small epiotic would have appeared, as we shall see in our next example. The "pterotic" region is small and unossified; it will be divided equally between the already large prootic and the alisphenoid, but the bony centre itself has not yet shown itself to me in the Bird-class. The prootic (Plate XI. fig. 7, *pro.*) is a very *internal* bone, as in the Rhea; although large it is completely insulated by unchanged cartilage; half the arch of the anterior, and the posterior half of the horizontal canal are still imbedded in cartilage only. The orbito-sphenoidal laminæ are narrow (Plate XI. fig. 1, *o.s.*), intermediate in size between those of the Rhea and the Ostrich; but the presphenoid is not so *ornithic* as in the former, being deeper and broader; moreover it has, in accordance with that almost constant correlation of size and precocity, already appeared in the form of two oblong bony points on the right side, in the somewhat obtuse angle formed by the giving off of the orbito-sphenoid. This appearance of the presphenoid as two linearly arranged ossicles is a *lacertian* character, and breaks out here and there in the bird-class, e. g. *Pavo*, *Nisus*; but in the "Lacertilia" the anterior sphenoid is relatively very large —large, as it were, at the expense both of the alisphenoids and vertical ethmoid, and its development is by many centres of ossification. The interorbital "fenestra" is not half so large as in the Rhea (if it exists at all in *Struthio* it is but small and transitory); it is ovoidal in shape, and only bordered by bone at top. This bone is the upper and posterior part of the vertical ethmoid (Plate XI. fig. 1, *p.e.*), which is already large, and by the absorption (or non-development) of cartilage, deeply and broadly notched above; this notch (Plate XI. fig. 1, *i.e.s.*) is converted into a fenestra by the upper (connate) ethmoidal piece of bone, which is already closely adherent to the lower centre. The large hinder half of the lower bone is thickened by a nearly vertical ridge in its upper two-thirds, where the pars plana (*p.p.*) applies itself; above this is the descending plate of the upper bone, and this is very thin, for it lies between the olfactory crura. The nasal process of the intermaxillaries reaches the front of the upper bone, and the lower bone has only reached this (vertical) line; all in front of this is still cartilaginous, one flat vertical plate reaching to the body of the coalesced intermaxillaries. In the groove below, where these bones have completely fused, there is the merest trace of the intermaxillary axis, or prenasal cartilage (Plate XI. fig. 2, *px.*), which is thus seen to disappear much earlier in the Emu than in its congeners. But the fate of the axis of each palatine arch is very different, its ossification being so early, and its importance as a persistent bony part being so great. The anterior bone, the palatine (Plate XI. fig. 2, *pa.*), is at an unusual distance from its fellow, because of the very out-turned forks of the vomer (*v.*) behind; this is the case quite as much as in the Ouaran Lizard (*Psammosaurus scincus*), but the long styliform ends of the pterygoids (*p.g.*) creep on to the vomerine forks, and thus approach the mid line more closely. Each palatine is a low triangle, the apex of which is the proximal (orbital) part, the anterior basal angle being prolonged into a small style, fitting inside the inner retral process of the prevomer; the posterior basal angle is blunt, and lies outside the pterygoid (Plate XI. fig. 2). The basal part of this triangle is thick; the rest, or inner part of the bone, is thin and delicately reticulate; it will be absorbed considerably in the centre. The pterygoids (*p.g.*) are thick and terete behind, flat and splintery for four-fifths of their extent; an oval sinuous condyle at the extreme end of each fits (by a synovial joint) on to the pterygoid facet of the os quadratum (Plate XI. fig. 2, *q.*); but the facet on the pterygoid is continued round the inner edge, because the lower half of the condyle is jammed in between the os quadratum and the anterior pterygoid process (Plate XI. fig. 2). The structure of these parts is a sort of morphological halting between the ornithic and the reptilian types; but the spur of the basitemporal which stands out against the pterygoid of the Lizard never articulates with that bone in birds, and in them is seldom developed to any extent; it is very large on each side, however, in the King Vulture, and in the so-called *Dinornis casuarinus*, Owen, a gigantic pickaxe-headed Rail (see Zool. Trans. vol. iii. pl. 52 for beautiful figures of this (?) extinct bird). On the other hand, the true azygous basisphenoid is aborted in all the Lacertilia, and therefore those spurs of it which culminate in the Struthionidæ, exist persistently in nearly half the ornithic genera, appear in the embryo of all, and reappear in the Cavies amongst the Mammalia, have no existence in the Lizard-tribe. A misapprehension of the nature of these spurs, and of their relations, has vitiated much that has been written upon this subject, and quite prevented anatomists from educing a true harmony of the parts.

The os quadratum (Plate XI. figs. 1, 2, *q.*) of this young Emu is wedged between and packed amongst its surroundings much more like its counterpart in the Tortoise than the same bone in the typical bird, so delicately hinged, and so free in motion.

The close adhesion to it, in an embryonic manner, of its own splint, the squamosal, (*sq.*), contributes much to this fixedness; in the typical bird the squamosal becomes much more mammalian, and after helping the prootic to form a glenoid cavity for the anterior or outer head of the bone, then stands off from it to allow of great freedom of motion. In all birds, as in Lizards, the large head of the quadrate bone reaches the exoccipital, passing over the lateral (tympanic) part of the opisthotic; in the Chelonian this latter part is so large that it receives the most backwardly projecting part of the condyle, and excludes the exoccipital from the hinge; still by far the greater part of the descending plate of the investing mass, in the auditory region, goes to form the mandibular suspensorium, whilst only a little of its *hinder* and *inner* part is devoted to the stapes, so contrary to what obtains in the ichthyic type.

The proper positive explanation of the bearings of these parts is not to be given by a reference to the uses and fitnesses of them in their last or osseous stage, but by reference to their primordial condition at a time when the thickening mass of cells around the cephalic part of the notochord was growing equally over the simple (cutaneous) auditory sac, and over the medulla oblongata, as the incipient occipital arch. At that time this continuous tissue sent down, amongst others, the mandibular ray, the thick upper part of which, as soon as chondrification commenced, appeared as a mass of cells, distinct both from the side of the skull above and from the top of MECKEL'S cartilage below. This great proximal expansion of the mandibular arch is a correlate of the arrested, starved condition of its serial homologue next behind. In the cartilaginous stage of the skull there was no definite boundary-line between the auditory capsule and the occipital arch; afterwards the bony pieces that result from the calcareous metamorphosis of the cartilage in certain territories intercalate remarkably, and interchange not only function but existence as we pass from group to group of the Vertebrata. Thus from one common morphological stem there springs an endless variety of detail,—detail, unimportant as to essential nature, but exquisitely fitted to the needs of each of the many myriads of species possessing the vertebrate type of structure*.

The extreme occipital end of the condyle of the os quadratum in this Emu-chick, most of the metapterygoid process, and a thin stratum of the base of the bone, are still unossified; the clubbed metapterygoid is characteristically struthious (Plate XI. fig. 1). In some points the ossific process is more precocious in the Emu than in the Rhea; in others it is slower. The "articulare" (Plate XI. fig. 6, *ar.*) is equal already to what we see in the Rhea a week further in advance; it is developed by an upper (articular) and a posterior lamina (Plate XI. fig. 4, *ar.*); these have already coalesced through the thickness of the cartilage; MECKEL'S cartilage is much more wasted than in the full-timed Rhea (Plate XI. fig. 5, *mk.*). The external splints (dentary, surangular, and angular) and the internal (splenial and coronoid) (Plate XI. figs. 1, 4, 5, & 6, *d.*, *sa. a.*, *cr.*, *sp.*) are in an excellent stage for comparison with those of the Reptile, being exactly in that stage of completeness and yet distinctness which is persistent in the cold-blooded "Sauropsida." The anterior part of each dentary forms with its fellow (Plate XI. fig. 5, *d.*) a beautiful outspread structure, a close counterpart of the next arch but one in front (the intermaxillary) (Plate XI. fig. 3, *px.*), and well illustrating the extreme licence taken by a secondary or splint bone, after having once originated in its simple primordial model. The state of things here, before MECKEL'S cartilage is removed by absorption, is very similar to the relation existing between the wide-spread growth of the fish's clavicle (coracoid of OWEN), and the feeble coraco-scapular cartilage within it (ulna and radius of the same author). The proximal splint of the mandible (the squamosal) (Plate XI. fig. 1, *sq.*) is still separate (above) from the great posterior sphenoidal operculum (the parietal) (*p.*), and there is no mistaking its homology with the so-called temporo-mastoid of the frog, and the preoperculum of the fish.

Above it the parietals have grown upwards to their junction at the sagittal line (Plate XI. fig. 3); they are already thick bones; the frontals (*f.*) have also met, but the anterior fontanelle (*fo.*) is a lozenge, with sides a line in extent; the posterior fontanelle is filled up by the apex of the superoccipital (*s o.*). Altogether this opercular roof is more convex than in the Rhea and the Ostrich; it remains so, though in a less degree, throughout life, thus bringing the Emu near to the Apteryx and the Tinamou in this respect. The original membranous skull is still to seen in the orbito-sphenoidal region; but the true relation of the frontal splint to the orbito-sphenoidal cartilage (Plate XI. fig. 1, *f.*, *o.s.*) is well shown at this stage by the manner in which the bony fibres of the orbital plate of the frontal are creeping over the outer surface of their cartilaginous model. Narrowing in front, the frontals run close upon the upper ethmoidal plate, and also passing by it become grooved to receive the pointed ends of the nasals (Plate XI. fig. 3). These latter bones (*n.*) are more ornithic than in the Rhea, having a slight descending process (Plate XI. fig. 1, *n.*): in this young bird the intermaxillaries separate them, the still ununited tips of these bones lying a little over the ethmoid (Plate XI. fig. 3, *n.*, *eth.*). Afterwards, in the adult, the nasals for some distance nearly approach; for the lengthening of the cranio-facial axis has by this time given a very lacertian shortness to the nasal processes of the intermaxillaries. Essentially, the lacrymals (Plate XI. fig. 1, *l.*), with their long superorbital process and their fenestrate antorbital plate, differ little from those of the Rhea; they are already well grown. The intermaxillaries (*px.*) have been partly described; the nasal portion is vastly different from the same process in the Rhea and Ostrich, being almost as feeble as in the Cassowary (Plate XI. fig. 3, *px.*). The extremely coarse vascularity of this part, as of the corresponding part of the dentaries, makes the bone like a Madrepore (Plate XI. figs. 1, 2, & 3); it is an excellent struthious character. The height of this part, in this young one especially, brings *Dromæus irroratus* very close to Professor OWEN'S *Palapteryx geranöides* (see Zool. Trans. vol. iii. part 5, pl. 54. fig. 1. p. 361). In this embryo the dentary margin of the intermaxillary is 1 inch 3 lines in extent, thus reaching to within 4 lines of the posterior end of the zygoma (Plate XI. fig. 1, *px.*), and well illustrating the potency of this most anterior arch, even in so simple and, as it were, elementary a bird as the Emu; and this is the bird in which I have found the best rudiment of the true maxillary bone (Plate XI. fig. 1, & Plate XIII. figs. 12 & 13, *mx.*). As in the Meckelian, so in the prenasal cartilage, there has been a much quicker absorption of substance: speaking of class characters, none could be more assuredly set down to the *mammalian* category; and the Emu, as one of the Casuarine group, is in many other respects the most outlandish of its class, and one of the nearest feathered relations of the hairy tribes. This early loss of the model has not, however, resulted in an earlier coalescence of the symmetrical splints; behind the coalesced part of the intermaxillaries the palatine plates (Plate XI. fig. 2, *px.*) are seen—much smaller, however, than in the Rhea, where the dentary margin is so short. The intense interweaving of the members of the struthious group is well seen here; for the African Ostrich rather sides with the Emu than with the Rhea in the structure of its intermaxillaries, and we shall see that in many points the Dinornis ties the Ostrich to the Emu. As to the prevomer of the Emu (Plate XI. fig. 2, & Plate XIII. figs. 12 & 13, *pv.*), its anterior process is smaller, and its body longer than in the Rhea, in which the widest part, viz. that bounding the middle nares, is short; next to it comes *Struthio*, then Dromæus, and then the Cassowary, in which the length and narrowness of the body of the prevomer rivals that of the Apteryx and the Tinamou. In the Rhea the two retral processes are of the same length; in the Emu the zygomatic style is very long, the inner style very short; the Ostrich agrees with the Rhea in this point. A few large foramina are seen on the palatal surface of this bone, which is gently concave; the upper surface is much more complex, and the bone unexpectedly takes on characters which have their fulness in the various tribes of typical birds. The ascending process (Plate XI. fig. 1, *n.p.v.*) is a mere bud, but more distinct than in the African Ostrich; the little bony bridge a little in front of this is similar; but whilst the posterior margin of that lamina is, in the Ostrich, not extended backwards, in the Emu it does grow both backwards and upwards, and swells into a thick-lipped shell of bone (Plate XI. fig. 2, & Plate XIII. fig. 13, *pv.*). This curious spongy shell is beautifully seen in the Eagle, and in many other birds: in some groups, for instance, all the "Lamellirostres," including the Palamedeas, the bones meet and coalesce along the mid line—a curious anticipation of the precisely similar junction of the maxillaries in all the Mammalia, and in the Crocodiles. This prevomerine bridge is well shown in Mr. ERXLEBEN'S figure of the Balæniceps' skull (Zool. Trans. vol. iv. pl. 65, figs. 7 & 8, p. 297, there described by me under the name of Turbinals, or "Ethmoidal pterapophyses").

---

* All this is self-evident enough to those who have grown weary of working backwards, but which must be repeated again, "line upon line and precept upon precept," to those whose intellects have not been severely trained by patient labour in the science of development.

The vomer (Plate XI. fig. 2, *v.*) in this embryo of the Emu is more than an inch in length, nearly half the length of the whole skull and face; as before mentioned, it is extremely divergent behind, and like the Ostrich's vomer it is trifurcate in front; the middle prong is very long and slender.

In this bone the Emu agrees with the Great Ostrich and not with the Rhea and Cassowary, which have it bifurcate at both ends. The two ends of the Emu's vomer are more nearly on the same plane than in the Rhea, where it comes nearer that of the Chelonian; in the next stage (six weeks old), at any rate in *D. Novæ Hollandiæ*, the vomer is straighter still. The long middle prong of the vomer in this early specimen reaches to the very extremity of the septum; but only the premaxillaries wrap themselves round the prevomerine rod—the approximated and coalesced "trabecular horns." But typical birds teach that the whole base of the septum proper belongs to the intermaxillary apparatus.

The bones that form the zygoma are very feeble, but they are all present in this and in a few other birds. The first or true maxillary (Plate XI. fig. 1, & Plate XIII. figs. 12 & 13, *mx.*) is 5 lines long by ½ a line in thickness; it is pointed at both ends, and lying close above, scarcely reaches as far backwards as the very prolonged angular process of the intermaxillary. This last process, the zygomatic process of the prevomer, the maxillary, and the zygomatic bone (jugal) (*j.*), are all tied together at one point external to the junction of the palatine with the inner retral process of the vomer. The jugal is twice the length of the quadrato-jugal (*q.j.*), which lies principally on the inside of the zygoma, and they are each of them twice as thick as the maxillary. At this stage the broadening of the whole palate has removed the maxillary and jugal one line from the outer edge of the palatine even at its nearest part (Plate XI. fig. 2).

The lingual cartilages (Plate XI. fig. 8) and the auditory columella (Plate XI. fig. 7) are in much the same condition as in the Rhea at the full period; only the columella and the lower thyro-hyal are ossified, and that not perfectly. The basihyal has sent backwards a uro-hyal (*b.h.*, *u.h.*) process which is a step in advance of the Rhea, whilst both these birds have the cerato-hyals alike in form and much more perfect than in *Struthio* (Plate XI. fig. 8, *c.h.*).

Dromæus, "B."

In this specimen I have not only to describe a difference of age, but also a distinct species. Drawings made by me twenty years since show in a very strong light the difference between the Emu with a somewhat pointed beak, and with a straight culmen, *D. Novæ Hollandiæ*, and the *Roman-nosed* kind, which has been termed (*op. cit.*) *D. irroratus*. My early observations on the latter kind were made on the skeleton of an adult individual in the Museum of King's College, London; those upon *D. Novæ Hollandiæ* were from a young bird (six weeks old) which I obtained early in the year 1844 from the Aviary of the late Sir ROBERT HERON *. This young individual I will now describe; and this description and my figures can be compared with the subject of them in the Museum of the College of Surgeons. Although in full age the bill of *D. irroratus* acquires a slightly decurved condition, yet that which I have described is very straight, and the contrast between it and this young *D. Novæ Hollandiæ* is very marked. Here the more delicate bill reminds one much more of the Tinamou, and even of the Apteryx, than the Roman-nosed kind, where the face is much more like that of the Goatsucker, and the bill very convex at its setting on, not gently arcuate altogether, as in this species.

This is a very valuable morphological stage, for there has been but little coalescence, and yet the bones have become closely contiguous; there are also some new bony pieces; the diplöe also has begun to form freely in the interspace between the outer and inner laminæ. The part taken by the basioccipital (Plate XII. fig. 2, *b.o.*) in the formation of the condyle is well seen, the sides only being formed by the lateral elements: on the whole, this transverse and somewhat dimpled condyle is very reptilian, and so is the whole of the basal bony piece. In the Rhea the oblong basioccipital is very *mammalian*; but here it is elegantly lozenge-shaped, its sides jutting out so as to form not much more than a right angle, the anterior part of the bone being wedged in between the basitemporals (*b.t.*). Altogether this bone and the basal parts of the sphenoid form a mysterious combination of the characters of the Lizard and the Guineapig (*Cavia aperea*), and it is most instructive to see this in a bird which seems like the first rude sketch of the feathered type of Vertebrata.

The large exoccipitals (Plate XII. figs. 1 & 4, *e.o.*) are now well formed, and appear larger than they really are, because of the addition in their upper edge (outside) of the large opisthotics (Plate XI. fig. 9, *op.*); the ends of the sutures between these bones are not as yet obliterated. The condyloid foramina, and that for the "vagus" (Plate XII. fig. 2), have a large margin of bone inside them, and are thus removed away from the basioccipital; the tympanic ala of the exoccipital (Plate XII. fig. 4, *e.o.*) is thick and clumsy, and is only very gently concave anteriorly, whilst in many typical birds, *e. g.* "Turdinæ," "Emberizinæ," "Picinæ," "Anatinæ," it forms a large part of their very elegant "bulla tympani." The large pentagonal superoccipital bone (Plate XI. fig. 4, *so.*)

---

* These came originally from the late Earl of DERBY's Collection.

is completely ossified, and the sinus canal is well walled in; the whole region is very similar to what is seen in the Apteryx.

Inside the skull the opisthotic is seen as a distinct wedge of bone, with its sharp end downwards, but the superoccipital has taken up most of the epiotic region—not all, for this bone, although small, is now to be well seen, roofing in the little lateral lobe of the cerebellum behind. The external lamina of the epiotic (Plate XI. fig. 10, *ep.*) is only to be seen by paring away the large outer angle of the superoccipital; the bone is subquadrate, gently concave within, whilst on the outside it is as gently convex. The external surface of the bone is absorbed towards the mid line of the skull to form a large pneumatic foramen, which connects the hollow interior of the bone with the diplöe of the superoccipital. Inside the skull, both below and above the small epiotic, a small synchondrosis exists between the prootic (Plate XI. fig. 10, *pro.*) and the superoccipital; the upper is the largest, and is at the anterior third of the great anterior semicircular canal (*a.s.c.*); the rest of the large prootic is well ossified, both within and without. The nature of the bar of bone formed by the opisthotic (Plate XI. fig. 10, & Plate XII. fig. 5, *op.*), which separates the auditory fenestræ (f. ovalis and f. rotunda), can be well seen at this stage; above the head of the "stapes" (Plate XI. fig. 10, *st.*), which lies in the fenestra ovalis, the suture separating the epiotic from the opisthotic (Plate XII. fig. 5, *ep. op.*), externally, is well shown. Returning to the base of the skull, we find the combined basitemporals and basisphenoid (Plate XII. fig. 2, *b.t.*, *b.s.*) forming a very elegant structure; the former are oval masses 2 lines across, the latter is seen as a large four-winged mass, sending forwards a long, gradually attenuating style (*r.b.s.*). One very small passage still exists in the front of the pituitary space, which has become convex by a triangular mass of bone with the apex forwards; laterally the Eustachian grooves (Plate XII. fig. 2, *Eu.*) have become much better defined; behind them we see the internal carotids (*i.c.*) grooving the basitemporals. The "posterior pterygoid processes" (*p.r.p.*) are extremely large, and cellular anteriorly, the scooping of each plate passing into one common vacuity in the very body of the basisphenoid; all this is truly ornithic. The bone is very wide between the "anterior pterygoid processes," which project outwards, downwards, and a little forwards. Where the basisphenoid meets the basioccipital below, it is somewhat split (Plate XII. fig. 2), and here the suture between the lateral and median basisphenoidal elements can be still seen; the basitemporals are dentate, as they underlap the occipito-sphenoidal synchondrosis; a little cartilage separates them from the basioccipital behind these teeth. The delicate pointed end of the rostrum (*r.b.s.*) reaches to the same vertical line as the front of the upper ethmoidal plate; it lies in the well-marked vomerine groove.

The prepituitary portion of the basisphenoid (Plate XII. fig. 1, *b.s.*) is still 4 lines from the ethmoid; the well-ossified alisphenoids have, at their supero-external angle, a small epiphysis, the "postfrontal" (Plate XII. fig. 1, *a.s.*, *p.f.*). The bony centre at the junction of the orbito-sphenoids with the descending presphenoidal plate is now enlarged (Plate XII. fig. 1, *o.s.*); the two pieces have become one, and this is spreading into the alæ; it commenced in this case in the floor of the skull; in the young *D. irroratus* the two bony points began in the angle on the right side. The interorbital fenestra (Plate XII. fig. 1, *i.o.s.*) is small and very high up, and the interethmoidal fenestra (*i.e.s.*) is increasing; it is twice the size of the other. The large, irregularly V-shaped vertical ethmoid (*p.e.*) bounds most of this fenestra; its sutures (in front and behind) with the upper oval bone (Plate XII. fig. 3, *eth.*) are not yet obliterated; that behind is best seen. The descending part of the upper bone is thick both before and behind; above the fenestra it is extremely thin. All the rest of the cranio-facial axis is still unossified, and the septum nasi (*s.n.*), which is deeply emarginate in front, has (relatively) retreated far back; the prenasal cartilage has become a mere thread of tissue; the whole of the rest of the olfactory cartilages are still soft.

The axis of the palatine apparatus is different from what we saw in the almost ripe embryo; for the pterygoid is more outspread (reptilian), whilst the anterior part of the palatine has become elongated (Plate XII. fig. 2, *p.g.*, *pa.*), and the broad part thinner in the middle, the absorption of its substance having increased. The metapterygoid process of the quadrate bone (*q.*) is still unossified to a great degree; if an epiphysis were to develope in this cartilage, we should have the metapterygoid of the Fish, the Lizard, and the Python*.

The "articulare" (Plate XII. fig. 1, *ar.*) is now a curious, thick, three-faced wedge of bone, and the Meckelian rod is gradually wasting.

The os hyoides has acquired a basi-hyal bone; the uro-hyal, although continuous, is still cartilaginous, as are the cerato-hyals, the upper thyro-hyals, and the ends of the lower thyro-hyals.

The squamosal (Plate XII. figs. 1–4, *sq.*) is already very thick, and the "zygomatic process," instead of joining the malar, as in Mammals, grows down the quadratum to the very edge of the articular cartilage. It may not be easy for the mere anthropotomist to see the relation of the squamous part of the temporal to the little "incus," but the problem is soluble enough in this young Emu; a splint could not be put on better than this is. The five pairs of *secondary* pieces (Plate XII. fig. 1) in the lower jaw are all distinct, but are well grown; the coronoid is the shortest, does not rise to the edge of the jaw, and has nothing whatever to do with the coronoid "process" of the dentary in the Mammal. As for the true maxillary, it has either not been ever separate, or it has already coalesced with either the malar or the prevomer; the jugal and quadratojugal (Plate XII. figs. 1, 2, & 3, *j.*, *q.j.*) together form a round style.

I have already spoken of the decreased width and lessened elevation of the premaxillary; its prenasal groove is almost extinct (Plate XII. fig. 2, *p.x.*); there is a large slit in the palate behind the solid part of the intermaxillaries. The prevomers are very thin, and studded with small irregular fenestræ (Plate XII. fig. 2, *p.v.*). The middle fork of the vomer has become less than the lateral ones in front (*v.*), the middle of the bone has become higher, and the hinder forks still more divaricate. The descending process of the nasal is nearly obsolete (Plate XII. fig. 1, *n.*); the broad upper part has spread further over the upper ethmoid (Plate XII. fig. 3, *eth.*). No important change has taken place in the lacrymals (*l.*), but the frontals and parietals (*f.*, *p.*) have become much more developed than in the nearly ripe chick. Even the upper fontanelle (Plate XII. fig. 3) is nearly filled up; but there are still two orbital fontanelles, the orbital plate of the frontal being very narrow at present, but closely adherent to its own cartilage—the orbito-sphenoid.

---

* In my paper on the "Gallinæ," p. 221, I have spoken of the absence of the metapterygoid in certain groups of the Vertebrata, amongst them the Ophidia; since then I have found it very distinct on the *front* of the os quadratum in a half-grown *Python Sebæ*, the gift of Mr. WATERHOUSE HAWKINS, and in other non-venomous snakes.

Dromæus, "C."

The third stage of the Emu's skull is that of a young of the freckled species (*D. irroratus*), evidently about two months, or perhaps ten weeks old [*]. There is in this a considerable advance on the last; and as this skull was partly disarticulated by maceration, I shall speak chiefly of the axial bones; and it must be remembered that although the two Emus are closely related species, yet some qualification must be made in the comparison of stages of birds only *generically* the same.

The triple nature of the transversely oval condyle of the occiput (Plate XII. fig. 6, *o.c.*) is well seen, the lateral elements almost meeting on the upper surface of the mesial piece. The basioccipital (Plate XIII. fig. 1, *b.o.*) ends much more bluntly forwards than in the last, and is very thick as well as very broad; it reaches out on each side in a sharp angle; the broad anterior margin makes the basitemporals diverge more than in the last. The exoccipitals (*e.o.*) are very massive; together they only form half the foramen magnum (Plate XII. fig. 6.), more than a fourth of which is completed by the superoccipital (*s.o.*) above. The opisthotic has still only half its suture (in the middle) obliterated (Plate XII. fig. 6, *op.*); it has to be deducted from the exoccipital. The superoccipital forms a very elegant crown to the occipital arch (Plate XII. fig. 6, *s.o.*); a blunt keel has appeared on the mid line; within, half the anterior and most of the posterior vertical canals (Plate XIII. fig. 4, *a.s.c.*, *p.s.c.*) can be seen in its substance.

The inner part of the opisthotic has not hastened to coalesce with the exoccipital (Plate XIII. fig. 4, *op.*), and the small squarish epiotic (Plate XIII. fig. 4, *ep.*) is still quite distinct. The exorbitantly large prootic (Plate XIII. figs. 1, 2, 3, & 4, *pro.*) has six irregular sides, and convexities and sinuosities without number. Below, it articulates by a dentate suture with the basioccipital (*b.o.*), in front, by a similar suture with the alisphenoid (*a.s.*). On the thick rounded upper surface the equally thick parietal rests, whilst the outer scooped surface is shielded by the incudal splint (squamosal), just hiding from view the extensive suture connecting it with the opisthotic and the exoccipital (Plate XIII. fig. 2 shows these removed); above the opisthotic it articulates with the superoccipital, this suture being short without and of great extent within; the lower angle of the parietal hides this suture on the outside. But one of the most important relations of the prootic is that with the basisphenoid, viz. at its antero-inferior edge (Plate XIII. fig. 2). The suture of the prootic with the basioccipital lies at an obtuse angle to that with the basisphenoid; above this line of suture, and in front of the groove in which the trigeminal nerve lies (Plate XIII. figs. 2 & 3), a knob-like mass of the prootic is jammed into a rough cup in the basisphenoid, between the thick divided posterior clinoid bridge (*p.cl.*) and the outspread "posterior wings" (*p.r.p.*). The antero-inferior part of the prootic within (Plate XIII. fig. 4) is smooth, convexo-concave, the scooping being at the mid line and below, for the bone thickens round the "internal meatus" (Plate XIII. fig. 4); external to this thickening the prootic is hollowed, in continuity with the concave surface of the alisphenoid. Between the meatus, with its thickened margin and its drilled fundus, is the deep well-like recess for the lateral lobe of the cerebellum (Plate XIII. fig. 4); and in the back of this mass, towards the top, is the epiotic (*ep.*). Here is seen the suture between the prootic and superoccipital, this suture being interrupted by the intrusion of the inner face of the epiotic. Down in the depths of this pit can be seen a right-angled smooth facet of the exoccipital; below the lower junction of the prootic with the superoccipital comes the head of the opisthotic (inner) wedge (Plate XIII. fig. 4, *op.*); and the lower margin of the superoccipital is viewed resting upon the prootic in front, the opisthotic in the middle, and the exoccipital behind.

---

[*] Lent me by Mr. FLOWER, the eminent articulator.

This may be complex enough, but the heaviest part is to come; and those who have merely studied anatomy in the pleasing works of the transcendentalists, and who have learned that both the basisphenoid and the presphenoid are found in the chondrified sheath of the notochord, and that to be well seen in the bird they must be separated by *a saw*, seeing that they are unhappily *connate*, will be rather staggered by the actual bones figured in these Plates, and to be now described *.

Undoubtedly the basisphenoid of the bird is the most remarkable of all known bones, and a knowledge of its development is fundamental to the study, not only of the ornithic skull, but, indeed, of all other skulls. For the skull alone, to say nothing of the corporal part of each vertebrate *microcosm*, has on it the impression and obsignation of the great universe itself; and "the edifice of this universe is, in its structure, to the human intellect contemplating it, like a labyrinth; where from all sides there present themselves so many ambiguous pathways, such fallacious similitudes of things and their signs, such oblique and interwoven knots of nature; and the journey over it is to be constantly made under the uncertain light of the senses, sometimes shining out, sometimes hiding itself, through the forests of experience and particular facts"*.

---

* "But this enslaved condition of the sciences is nought else than a thing bred from the audacity of the few, and the sloth and pusillanimity of the rest of mankind. For as soon as any particular science has in parts been somewhat diligently tilled and laboured, some one has usually arisen, confident in his talent, and accepted and celebrated on account of the compendiousness of his method, who, in so far as regards appearances, has established the art, but in reality has corrupted the labours of his predecessors. Yet what he has done is wont to be well-pleasing to succeeding generations on account of the easy utility of his work, and their wearisomeness and impatience of renewed inquiry."—BACON, Prolegomena to the 'Instauratio Magna.'

The prodigal development of the bird's basisphenoid (Plate XIII. figs. 1, 2, & 3) is seen, not merely in its breadth but also in its length, reaching, as it does, sometimes to the furthest end of the base of the nasal septum; in its vertical growth also, seeing that it shoots upwards to form a very considerable moiety of the interorbital septum, and in thus joining the great vertical ethmoid, leaves but little territory to the presphenoid. In these generalized birds (the Ostriches), so near to the Reptiles and to the Mammals, it might have been expected that the basisphenoid would have derived a feebleness on both hands, from its relation to that of these outlying congeners. In one respect it does so, viz. in the symmetrical *autogenous* basitemporal portion; not so the azygous piece, or true basisphenoid; for here in these very birds its transverse growth attains its fulness: every one will see that a free growth of the "investing mass" lies at the root of this matter.

Compared with the last specimen, the basitemporals (*b.t.*) are nearer together at the mid line, and do not underlie the basioccipital; in front of the fossa which separates them the pituitary floor is convex and somewhat perforate. The Eustachian canal Plate XIII. fig. 1, *eu.*), membranous below, and the deep fissure between the anterior and posterior pterygoid processes, are well seen (Plate XIII. fig. 1, *a.p.*, *pr.p.*); as also the curve of the great subcylindrical anterior wing, with the somewhat sudden narrowing of the prepituitary, high, vertical portion, as below it passes into the rather slender rostrum (*r.b.s.*), which shows its shallow groove, in the upper view, to receive the trabecular structure; for the rostrum itself is altogether a subtrabecular structure. It would not have been altogether *below*, but *between* as well, if the trabeculæ had not coalesced together. The oval crown of the high prepituitary mass is the *connate* anterior clinoid process (Plate XIII. fig. 3, *a.cl.*), behind which is the transversely oval, deep, backwardly curved "sella turcica" (*s.l.t.*), into the fundus of which the carotid canals open.

Behind this pituitary "well," and between the thick crests of the posterior pterygoid processes, is the posterior clinoid bridge (*p.cl.*) in the "middle trabecular region:" a slit divides it at the middle, and this slit passes down the oblique, gradually narrowing, postpituitary mass (Plate XIII. fig. 3). The embryonic skull explains this; for after the investing mass has increased around and in front of the pointed end of the notochord, it gradually, whilst separating that structure from the pituitary body, grows round this body, the cartilage into which the mass is being metamorphosed meeting behind to form the posterior clinoid wall, and growing up from the edges of the trabecula in front of the pituitary body to form the anterior clinoid mass. The broad band of tissue behind the "infundibulum" must coalesce more slowly than that in front of it, even in the process of chondrification; this is repeated when that cartilage is metamorphosed into bone. Whilst the lower lamina of the new basisphenoid is growing backwards, forwards, and a little upwards, the upper lamina of bone in the fundus of the "sella" is growing upwards right and left into the clinoid bridge and posterior pterygoid processes, and backwards along the floor of the skull. The two wings of this upper bony lamina only slowly meet behind the "sella," both above in the great transverse bridge, and below in the postpituitary skull-floor; hence the *slit* which for a long while is seen at the mid line in this and other birds. In the side view, the slit which separates the high prepituitary mass from the root of the rostrum below (Plate XIII. fig. 2, *b.s.*, *r.b.s.*), shows how that this rostrum is an extension of the secondary growth of cartilage below the "infundibulum," and altogether distinct from the trabeculæ; the late-formed cartilage of this floor and its rostral prolongation, however, is soon formed into a continuous mass with the cartilaginous trabeculæ. A front view (Plate XIII. fig. 7), supposing the rostrum to be severed at its free part, shows the structure of this bone well, and also that the posterior pterygoid processes lie on a *higher* plane than the spurs in front of them. This extension outwards of the great basisphenoid is a correlate of the *transverse* position of the alisphenoids, which are best seen, not at the sides, as in most vertebrata, but in *front* (Plate XIII. fig. 7, *a.s.*), as they form the large posterior walls of the orbit. These irregularly pentagonal bones are only gently convex at or near the outward (posterior) margin; much of their orbital surface is smoothly flat as they approach, thin and splintery towards the small anterior sphenoid. Although subpentagonal, each side of the alisphenoid is rounded or convex; the external and lower margins are thick; the outer (upper) angle has a feebly expressed epiphysis, the postfrontal (*p.f.*); whilst the lower margin is deeply scooped near the inner and the outer cornu; with the help of the basal bones, these notches are converted into the foramina ovalia (5), and rotunda (5, *a*). Between these bones and below and behind the presphenoid is the large semicircular "common optic foramen" (2); the anterior sphenoid is connected with the alisphenoid by mere fibre (Plate XIII. fig. 7, *p.s.*), a remnant of the original membranous skull, and now forming part of the "postorbital fontanelle" of each side; a remnant of this exists in the adult; periosteal layers of bone have filled up the rest. The presphenoid and ethmoid (Plate XIII. fig. 5, *eth.*) are still separate; the two moieties of the latter have quite coalesced; it is a large bone; its alæ are ossified almost as far as in the adult; and the fenestra is somewhat more circumscribed by periosteal layers. The bone has still territory, fore and aft, in a cartilaginous condition, but it has reached the rostrum below; seen from behind (Plate XIII. fig. 6) the olfactory notches show themselves above that upper bar, which ultimately joins the presphenoid. The lower part of the turbinals (antorbital, "pars plana vel papyracea") is still wholly soft, and wholly separate, except by a fibrous connexion from the perpendicular plate.

---

* Bacon.

The fenestra in the antorbital plate of the lacrymal is well shown (Plate XIII. fig. 8); as also the splints of the lower jaw (Plate XIII. figs. 9–11). Whilst much of the outer and anterior part of the articular cartilage is still unossified, yet at the apex of the internal angular process (Plate XIII. fig. 9, *p.fo.*) the pneumatic foramen is well formed, and the interior of the bone is being absorbed on one side, whilst it is only forming on the other. The articular cartilage is carefully wrapped in its splints before ossification commences; when their *model* is fully ossified, then they coalesce to a great extent.

Dromæus, "D."

My fourth specimen of the Emu was put into my hands in an unmacerated condition by Mr. BARTLETT; it had died on its voyage from Australia, and was of the freckled kind (*Dromæus irroratus*, Scl. and B.). This individual was but little older than the last, yet some important changes have taken place; there are also some individual differences; and besides this, as it was in a fresh state, I am able to give drawings and descriptions of the complex nasal cartilages. The cranial part is very high, and smoothly ovoidal; indeed its form is such as is found in the young of the Great Ostrich when the entire chick is no larger than a sparrow, *Struthio*, "A;" the frontal convexities over the hemispheres have a peculiar fœtal character, although the bird was fully half the size of the adult. In respect of its roundness this skull comes near that of the Apteryx; but that which distinguishes the latter bird is the great size and breadth of the occipital region as compared with the rest of the skull, a character which it shares with the lowest monotrematous and placental Mammals, e.g. *Echidna*, *Ornithorhynchus*, *Sorex*, and *Talpa*. In this specimen of *D. irroratus* the basisphenoidal rostrum is deeper and more cultrate than in the last, and there is a more marked remnant of the pituitary space; the basitemporals do not converge so much, and consequently the occipito-sphenoidal synchondrosis is better seen below.

The postfrontal is scarcely more developed, being almost entirely cartilaginous, and the descending plate of the presphenoid is still soft. The orbito-presphenoidal bone began at the top, in the skull-floor; the high part of the basisphenoid and the vertical ethmoid are still far apart. The ethmoidal "fenestra" is divided into two by a broad periosteal bar of bone, leaving only a small space membranous above and below.

The delicate maxillary style has partly coalesced with the styloid angular process of the intermaxillary; but for the early specimen its existence could not have been proved. The palatine fenestra has become definite; it is oval, and about $\frac{1}{9}$th of an inch in diameter.

The pterygoid is very flat, splintery, and unlike the elegant terete bone of the typical birds. The height of the intermaxillary in front, and the strength and form of the whole bone, reminds one strongly of the same part in *Dinornis robustus*, and especially of the subgeneric form, *Palapteryx* (Zool. Trans. vol. iii. pl. 54, where in fig. 1 the intermaxillary fragment is placed considerably too far from the skull). The os quadratum is a marvellously swollen clumsy bone, totally unlike its homologue in the most gigantic of the Rails—the mis-called *Dinornis casuarinus* (*op. cit.* pl. 52). As in the Blackbird (*Turdus merula*), the base of the stapes is perforate like that of the Mammal; this is caused by its having a large pneumatic hole on one side and a lesser passage on the other; the apex has a triradiate piece of cartilage growing from it.

The edges of the upper ethmoidal bone have not descended far into the aliethmoidal cartilaginous plates (Plate XII. fig. 7, *al.e.*, *eth.*); in the adult the bone grows downwards and inwards, and then stops, leaving the rest soft. To one fresh from the study of the nasal labyrinth in the Mammals, the extreme simplicity of the *olfactory region* in the Emu would be very perplexing; to one fresh from the study of this part in the lower Vertebrata, the complexity of that part of the nose of the Emu which is supplied by the fifth nerve would be just as strange. There is no discontinuity of the nasal cartilages in the Emu (Plate XII. fig. 7), such as we see in the higher birds, and yet the *regions* are not ill-defined. The three turbinals of Man and his alæ nasi supply us with familiar conceptions, and the ordinary works on human anatomy with familiar terms, yet these may be modified a little to suit wider groups, and the necessities of a fuller morphology.

The terms which I have been in the habit of using (see Zool. Trans. vol. v. pp. 149–242) are for the homologue of the upper turbinal "aliethmoid," for the middle "antorbital," or sometimes the old term "pars plana," for the root of the inferior turbinal "aliseptal," and "alinasal" for the alæ nasi.

When the turbinals of the Emu are seen from within (Plate XII. fig. 7, *u.tb*), the upper one looks to have a very large development; it is all hollow, and simple, however (Plate XII. fig. 8); for the aliethmoid, after growing outwards, turns round, and grows towards the axis of the skull; in doing so it grows upwards also, in a rounded manner. It then keeps (for some distance downwards, and much more in front than behind) near the perpendicular ethmoid, then makes a semicylindrical curve outwards; the lower edge of this outward part being continuous with the top of the pars plana (antorbital). In a vertically transverse section this simple cartilage presents the form of the letter S (Plate XII. fig. 8), there being a deep concavity on the inside, at the top; then a large convexity; then a deep, almost cylindrical groove separating the upper from the lower turbinal. On the outside the upper part is a semicylinder, then a flask-shaped cavity, with the neck behind, and then below it is the swelling top of the middle ethmoid. Seen from within, the upper turbinal looks like a miniature bagpipe with the broad end forwards (Plate XII. fig. 7). This is really the homologue of the cribriform plate (as well as of its turbinal outgrowths) of the Mammal; but here there is no sieve-like structure, and there are no lamellar outgrowths.

Close as we now stand to the Mammal, it is yet very hard to see the exact bearings of this subject: the present Hunterian Professor of Anatomy did once, with his keener insight, give the writer a clue to trace its mazes by; it has, however, required much persistent work to make it clear. The hole through which the olfactory crus of the bird passes out of the cranium into the orbit, is not a *single* representative of the *many* pores through which the olfactory filaments of the Mammal pass; the membrane which encloses that crus is really part of the skull-floor; and the chink through which the olfactory crus passes anteriorly, between the aliethmoid and the perpendicular plate, is the homologue of that vertical series of passages which lies nearest the crista galli of the Mammal. In the bird this chink is not subdivided, and the crus passes *in* to give off its filaments from its dilated end. In the bird the cranial cavity is aborted anteriorly by the upgrowth of the great interorbital septum; the crista galli underprops the frontals directly, and the posterior end of the middle ethmoid (above) goes far back to join the presphenoid. On the latter the olfactory crura rest; the sides of the former (the supero-posterior part of the middle ethmoid) are grooved to lodge them as they pass mesiad of, and over the large eyeballs to reach their destination. The posterior margin of the pars plana is thick and turned inwards, and stands upwards and a little backwards; nearly all its inner surface is occupied with an ovoidal tent-like outgrowth (Plate XII. fig. 7, *m.t.b.*, a bristle is passed into the opening), which is bifurcate a little below, and which, for the lower half of its anterior margin, is not confluent with the primary cartilage; this slit therefore opens into the deep crescentic groove which separates the upper from the middle turbinal. These two swellings lie near together, and the posterior end of the lower turbinal passes equally downwards and backwards beneath them (Plate XII. fig. 7, *i.t.b.*). This lower turbinal is not at all simple; it is complex beyond expectation.

As soon as the primary septal ala (continuous with the ethmoidal) begins to turn inwards, it becomes double (Plate XII. fig. 9, *al.s.*, *i.t.b.*), one lamina keeping the sigmoid curve of the upper turbinal, the other growing downwards, and then first outwards and afterwards inwards, to form the outer nasal wall; when it is nearly halfway down it gives off, from its outside, a small lamella which is connected by a fascia with the edge of the upper jaw. This fascia halfway down gives off a horizontal lamella (Plate XII. fig. 9), which joins the cartilaginous wall within; the cartilaginous plate nearly reaches the base of the septum nasi (*s.n.*), it becomes the ala nasi anteriorly. The inner sigmoid lamella (Plate XII. fig. 9, *i.t.b.*), which towards the septum is first convex, then concave, and then convex again, gives off truly cartilaginous secondary lamellæ, four of which bifurcate again, whilst five continue simple; so that in all there are no less than thirteen free plates. Behind, this great inferior turbinal becomes simpler (Plate XII. figs. 7 & 8, *i.t.b.*), and this part is seen from below roofing the middle nasal passage (Plate XI. fig. 2, *i.t.b.*); in front it does the same, and ends at the middle of the true ala nasi; this latter cartilage (Plate XI. fig. 3, *al.n.*) has no independent outgrowths of its own; it is very large and simple, and ends in a crescentic manner over the oblique anterior nasal opening. The somewhat thin nasal septum (Plate XII. fig. 9, *s.n.*) is one continuous sheet of smooth cartilage, and at first almost entirely fills up the space below the nasal processes of the intermaxillaries, to their solid part in front; afterwards, when ossified, it will be relatively much smaller. The manner in which the lacrymal embraces the lateral ethmoidal structures at every available point of contact (Plate XII. fig. 8, *l.*), shows its true nature as the protective "operculum" of this region; a band of cartilage, which becomes thicker-edged below, lines the front of the antorbital plate of the lacrymal almost to its edge; it is the lower and posterior part of the inferior turbinal (*a.i.t.*), and is often in higher birds an autogenous cartilage, to be afterwards separately ossified; and there is nothing in the bird's skull more curious than this lower "antorbital," which in certain species so closely imitates the "transpalatine" of the Reptile.

I have already spoken of the skull of the adult Emu, and shall here merely recapitulate some points, and add a few more. The drawings which were made by me many years ago from the specimen of *D. irroratus* in the King's College Museum, need not be given.

The sutures both above and below are nearly obliterated from the skull proper; a little of the sagittal suture is seen close behind the *exposed* upper ethmoid; the nasal processes of the intermaxillaries (thoroughly confluent) do not reach to this broad plate. The characteristic lateral groove in the side of each intermaxillary and dentary is intensified in size and depth. The terminal diverging rami of the vomer have become more divergent, and the palatine fenestra has become so large as to make the bone a mere irregular ring. All the bones of the maxillary and intermaxillary regions keep their distinctness. The aliethmoid has become bony further down, and has joined the ossified pars plana; the interorbital septum has lost its fenestra, being filled up with periosteal layers, and the nasal septum, now relatively less, has become ossified continuously with the ethmoid.

Casuarius Bennettii (The Mooruk).

I have been very fortunate in obtaining from the Gardens of the Zoological Society two young Mooruks at the time of hatching, both imperfect, but the one more than supplementing the other. It is not for nothing that the Cassowary has a sort of porcupine's quills growing out of its wings, as though it were contemplating the shearing of all its (very simple) plumes, ready to become one of the hairy class—the Mammals. I was not aware, and I had it from the mouth of my friend Professor HUXLEY that he was not aware, how much of the essential mammal there is hidden under the plumy cloak of the Cassowary; and yet, compared with other birds, the Cassowary is *low* and *reptilian*; what the Chimæra is to the more elegant typical fishes, that the Cassowary is to ordinary birds; not, indeed, to the same extent is this difference, yet it is the same in kind.

These strong-bodied *borderers*, having certainly laws of their own, are yet only partially amenable to the law (morphological law) of the more inland tribes of the regions between which they lie. Here then the morphologist has presented to him one of those "oblique and interwoven windings and knots of nature" of which BACON speaks; and no little pleasure and profit will accrue to him who shall even partially untie a knot like this.

The ornithic discrepancies of this bird must be detailed now; and if the present paper should throw any real light upon the bearings of this bird's skull, and show how its morphology looks backwards to the cold-blooded classes, forwards to the Mammals, and upwards to the innumerable members of its own (feathered) group, my labour will not have been in vain.

The transversely oval occipital condyle (Plate XIV. fig. 2, *o.c.*) has on its upper surface a cleft, in which lie the compressed remains of the notochord; this condyle is not yet ossified. This embryonic remnant, a little further forwards, is enclosed in the cartilage, nearer the top than the bottom; it is gradually lost in the basioccipital bony centre.

This centre (*b.o.*) would be elegantly lozenge-shaped, were it not that the front and the hinder angles are premorse; it is *reptilian* in its lateral angular extension, as in the Emu. The growth of the exoccipitals (*e.o.*) in all directions has caused the vagus and condyloid foramina (8, 9) to be enclosed in bone, the condyle to be protected by bone laterally, and the opisthotics (outer laminæ) to be no longer distinct from the outer part of these occipital arches (Plate XIV. fig. 4, *op.*); they are at present, however, mere islands of bone, being completely surrounded by cartilage, save at the opisthotic or upper margin, externally. A distinct tract of cartilage separates the lateral from the upper occipital (Plate XIV. fig. 2, *s.o.*); and the epiotic, the upper part of the opisthotic, and the outer part of the exoccipital regions are still unossified. The large superoccipital comes nearer to the pentagon in shape than in the other "Struthionidæ," the basal margin is much broader, and the sinus-passages (*s.c.*) are further apart. At the mid line this bone is feebly keeled; on the inside (Plate XIV. fig. 5, *s.o.*) its vicariously epiotic part is embracing the hinder half of the "anterior" semicircular canal (*a.s.c.*); whilst for a line in extent this canal is unossified, the rest is covered in by the prootic (*pro.*), but a large, vertically oblong tract of cartilage runs down from the top of the great canal arch to the top of the inner face of the exoccipital. The opisthotic lies close to this face in the inside (Plate XIV. fig. 5, *op.*), but is still separate, and a narrow strip of cartilage intervenes between it and the prootic; the epiotic has not made its appearance, and the fossa, under the great arch, where it should come is much shallower than in the other Ostriches (Plate XIV. fig. 5). The prootic is already large, its inner lamina being the largest (*pro.*); the two bony plates are fused together over the ampulla of the great anterior canal (Plate XIV. fig. 6, *a.s.c.*) (and indeed through the substance of the cartilage), save at their margins. A considerable mass of cartilage still separates the prootic from the basioccipital and basisphenoid below (Plate XIV. fig. 6); this is continuous with the remnant which intervenes between the two basal bones (*b.o.*, *b.s.*). A small patch of cartilage comes between the prootic and the alisphenoid, and there is no trace of the great "pterotic" crest of the fish (Plate XIV. figs. 5 & 6). A half-ossified band of cartilage runs across the "foramen ovale" (5), making it double, as in the Carp. If the semicircular canals were only walled in by a thin layer of bone, they would be seen to be marvellously like those of the Lizard; in both the Lizard and the bird these tubes and their bulbs are a very beautiful structure. The angularity of the basioccipital, and the two pairs of lateral outgrowths to the basisphenoid (Plate XIV. fig. 2, *a.p.*, *pr.p.*), mark the very mixed character of the skull-base of the young Cassowary, for the synchondrosis is nearly as fully seen below as above; more so than in any other bird, as far as I know. Yet at this very place we see an important embryological and, as it were, reptilian character; for the broadish terminal end of the basisphenoid is not only bifid, but the split is really an oval space (Plate XIV. fig. 2, *b.s.*), the remnant of the "posterior basicranial fontanelle" of Rathke. My earliest specimens of *Struthio camelus* do not show this; they only, like other birds, show the split above; so also neither the Emu nor the Rhea have this space below; and I have described an Emu a week younger than this Cassowary.

Not less unmistakeable is the *mammalian* nature of the small, *late*, long distinct basitemporals (Plate XIV. fig. 2, *b.t.*) or "lingulæ;" in *Struthio camelus* (B.), a stage of the embryo three weeks earlier at least, these bones had not only coalesced with each other, but also with the basisphenoid. In young ripe Crocodiles, the same stage as this Cassowary, a mere trace of the distinctness of these bones is seen. In *Chelone mydas*, at the same age, the sutures can be traced, and often for a long while in that group the basitemporals do not coalesce as I have seen in *Emys Europœa*, and as is well shown in Dr. Gray's figure of *Cyclanosteus senegalensis* (Zool. Proc. 1864, pt. 1. p. 96); but in that order, as in most Reptiles, these bones meet at the mid line, and extend through the entire substance of the basis cranii. But in the Mammalia, where for the most part these bones are quite lateral and very small, they continue distinct in some cases, e. g., in the Walrus (*Trichechus*), until the creature is well nigh full grown. Still in the Cassowary they retain the ornithic and reptilian function of forming a floor to, and helping to enring the internal carotid artery (*i.c.*), a vessel which takes shelter in the prootic, or the tympanic, or in both, in the Mammalia. The anterior and posterior pterygoid processes (*a.p.*, *p.r.p.*) are perfectly struthious, and there is not much to remark upon in them, save that they come very close to the same parts in the Emu, as in that bird the Eustachian tubes are merely overshadowed by bone, and open into one common palatine slit between and behind the (struthiously distinct) middle nares.

The "rostrum" of the basisphenoid (*r.b.s.*) is somewhat stronger than in the Emu, and is intermediate between that of the latter bird and the Rhea; it passes under the septum for a shorter distance than is usual in the Struthionidæ. The broad part of the basisphenoid is such as would be seen in the young Fowl if four-fifths of the basitemporals were cut away, leaving only a remnant at each hinder angle; thus exposing the synchondrosis of the two mesial bones, and laying bare the Eustachian trumpets. A layer of fibrous tissue separates the "rostrum" from the coalesced trabeculæ (Plate XIV. fig. 8) up to the high prepituitary part of the basisphenoid. The alisphenoids (Plate XIV. figs. 1, 5, & 6, *a.s.*) are relatively higher than in the other Ostriches, and they are not so ornithically transverse; there is a great approach to the lateralness seen in the Crocodile and the Mammal. They are ossified, save at the postfrontal spur (*p.f.*), in front of the divided "foramen ovale," and below; but the upper basisphenoidal lamella has nearly reached them on each side (Plate XIV. figs. 5 & 6); the "foramen rotundum" (5, *a*) is principally bounded by the cartilage which underlies the alisphenoid anteriorly. A broad right-angled space lies between the upper arched margin of the prootic and the sinuous posterior margin of the alisphenoid (Plate XIV. figs. 5 & 6); in the Fish this space is filled up by the great "pterotic" cartilage-bone, which has in front of it, and interlocked into it, an almost equally developed external alisphenoidal epiphysis—the postfrontal. The alisphenoid, in this as in the other "Struthionidæ," is a convexo-concave thick bone, its scooped part being within; it has no central "fontanelle" as in many birds; but, as is the rule in the whole class, an oblong fontanelle intervenes between it and the margin of the orbito-sphenoid (Plate XIV. fig. 1, *o.s.*).

This is a remnant of that extensive space in the Lacertian skull which extends from the Y-shaped orbito-sphenoid to the margin of the prootic, and which is somewhat defended by an upgrowing rod ("columella" of CUVIER) of the pterygo-palatine arcade. The whole of the anterior sphenoid (Plate XIV. fig. 1, *o.s. p.s.*) is still mere cartilage, and the wings, about 3 lines in extent, are only a line broad (Plate X. fig. 20, *o.s.*); *lateness* in ossification and stunted growth are, as usual, here associated. The interorbital "fenestra" (Plate XIV. fig. 1) is oval; the long diameter vertical, and it is 3½ lines by 2 in size; a full "line" of cartilage intervenes between it and the perpendicular ethmoid (*p.e.*). The continuous interorbital septum is very large, the orbit being 9 lines in diameter; thus the ethmoidal region is very large indeed, reaching behind over and below the whole fenestra, and in front taking in, without a notch or a change of tissue, all the way between the turbinals and the alæ nasi. Then it is not merely the height of the perpendicular ethmoid which gives it its great size, but the upper piece in this group of "Struthionidæ" takes on a monstrous growth. In all the members of the Struthious family the mode of ossification (by an upper and a lower centre) is peculiar; and so is the persistent exposure of the crown of the cranio-facial axis: this is normal in osseous Fishes; but in them, as in typical birds, the perpendicular bone reaches through to the top, and is not capped by a second piece.

It is the overgrowth of this upper piece (Plates X. & XIV. *eth.*) which gives the Cassowaries their great peculiarity; for in them it not merely *appears* at the surface, but it emerges, like the intrusion of a hypogene rock through the secondary strata of the earth's crust, leaving the frontals and lacrymals merely flanking its sides (Plate X. figs. 18 & 20, & Plate XIV. figs. 1, 3, 4, & 8). This is not like the account which is given of the Cassowary's crest in the Osteological Catalogue of the Museum of the College of Surgeons (vol. i. p. 259, No. 1356); but the distinguished author of that Catalogue had evidently not been so fortunate as to obtain the head of a Cassowary chick. I had compared the Ostriches to the Sharks and Rays long before I saw the meaning of the Cassowary's crest, but this huge swelling upgrowth of the anterior part of the primordial skull carries the mind back to the same part of the organization of the lower plagiostomes, e. g. *Chimæra* and *Callorhynchus.*

The crest of the adult Mooruk (*C. Bennettii*) has three thick convex ridges meeting at the top—one in a line with the axis of the skull, and the two others out-turned like the horns of the coalesced parietal bone in Lizards (see the excellent figure given in Dr. SCLATER'S paper on the "Struthionidæ," Trans. Zool. Soc. vol. iv. pl. 72). This curious ethmoidal horn-core, with its leaden-black horny sheath, is a pretty exact miniature of that strange old three-wayed bridge which may be seen in the small but extremely ancient town of Crowland, in the Fens of Lincolnshire.

At this early period there is no mark of the high three-rayed ridge; for the whole upper surface (Plate XIV. fig. 3, *eth.*), which has a lanceolate outline, is smoothly convex; but it is already a full "line" higher than the bones that flank it (Plate XIV. fig. 1.). If we turn to the figure of *Casuarius bicarunculatus* (*op. cit.* pl. 73), we shall see that the crest is arrested at this low simple condition; *C. uniappendiculatus* (*op. cit.* pl. 74) is intermediate between *C. bicarunculatus* and *C. galeatus* (*op. cit.* pl. 71), in which it attains its greatest actual height, although it retains the lanceolate outline. A section of the broad upper ethmoid of the Mooruk-chick (Plate XIV. figs. 7 & 8) shows that it is already one of the thickest bones in the skull; anteriorly (fig. 7) its arch is about one-third of a circle, further back (fig. 8) the arch is like that of a low-crowned bridge, and all this wide, less elevated hinder part is a mere hollow dome, being behind the supporting perpendicular plate, which, as a broad-topped wall, underprops the foremost part of this ethmoidal crest (Plate XIV. fig. 7, *p.e.*). Here one important difference presents itself: in the other already described "Struthionidæ," the upper plate sends down a keel between the olfactory lobes, and it is this part which is primarily thin, and always grooved for the lodgement of those organs; in the Cassowary, however, the vertical plate is completely formed by the middle or perpendicular ethmoid, which is as much expanded at the top as the upper ethmoid in the other Ostriches. The greatest fore-and-aft extent of the middle ethmoid (Plate XIV. fig. 1, *p.e.*) at present is 4 lines; but it has reached the upper ethmoid above, and has reached within a line of the basisphenoidal "rostrum" below. Between the lateral ethmoid (upper and middle turbinals) the bone is thin (Plate XIV. fig. 7, *p.e.*); but it is not fenestrate as in the Emu: this internasal "window" is very variable in the bird-class generally, existing oftener amongst water-birds than amongst the arboreal tribes. The rest of the cranio-facial axis is one continued, smooth, thickish, cartilaginous plate; there being no change as we pass from the vertical ethmoid to the septum nasi proper: this plate (Plate X. fig. 19, *s.n.*) fills up the whole of the large intermaxillary angle (*i. e.* between the body and its processes), as in the embryo of typical birds.

As in the other "Struthionidæ" and the Mammalia, there is a perfect continuity of all the nasal cartilages; the alæ that grow from the upper edges of the great general orbito-nasal septum being converted into cartilage by the metamorphosis of the whole of its simple cells, without any of that breaking up into distinct territories which we see in the purer bird-types. These upper olfactory wings extend on each side for a distance of 1 inch 8 lines, the whole length of the skull and face being 2 inches and 8 lines; for the hinder end of the upper ethmoid lies in the same vertical line as the common optic foramen, and the alæ nasi fill up the angle of the intermaxillaries on each side (Plate X. figs. 1 & 3). Posteriorly these long wings (connate in their bony stage) perform the rare function of largely helping, dome-like, to roof in the hemispheres of the brain (Plate X. fig. 20, & Plate XIV. figs. 1, 3, 4, & 8, *eth.*); in front they project somewhat beyond the most jutting point of the nasal septum to form the breath-valves. All these large birds, which "walk through dry places," have that part of the nose which is merely supplied by the nasal portion of the fifth nerve, very large (largest of all in the Cassowary), whilst the true olfactory region is small, and simple enough. The simple fold of cartilage (Plate X. fig. 17, *al.e.*, *u.t.b.*), which, turning abruptly inward, forms a triangular, somewhat swollen elevation outside the end of the olfactory bulb, is all we have here of that exquisitely perforate and highly complex mass which in the Mammal receives the name of cribriform plate and upper turbinal. Close on its outside, and towards the top, the nasal branch of the ophthalmic nerve (Plate XIV. fig. 7, *n.n.*) is seen creeping downwards to supply the rich outgrowths of the wings of the nasal septum. Below, the ethmoidal ala passes down into the pars plana (Plate X. fig. 17, & Plate XIV. fig. 7, *pp.*) behind, and into the nasal wall, which grows down from the root of the inferior turbinal. The pars plana is a high triangle, its base below, and it is somewhat convex; its free margin lies close to the perpendicular ethmoid, and on its inner face is the middle turbinal. This outgrowth (Plate X. fig. 17, & Plate XIV. figs. 9–11, *m.t.b.*) is a somewhat hourglass-shaped tent, with a small opening in front; it is gently convex above, then slightly concave, and then thickens into two converging roots below; it is 3 lines long by 1 in breadth. The position of this tent is oblique, for it passes downwards and forwards; a valley of the same breadth as this turbinal separates it from the infolded upper turbinal; below this *true* olfactory region lies the hinder part of the inferior turbinal (Plate X. fig. 17, *i.t.b.*, *a.i.t.*), the last folds of which can be seen in the middle nares, when the skull is looked at from below. Both the upper and lower turbinals lie in the orbit (Plate XIV. fig. 1), which is bounded in front by the descending portion of the large lacrymal (*l.*); inside this bone, and further forwards, inside the ascending plate of the prevomer (Plate XIV. fig. 1, *p.v.*), we have the inferior turbinal, which has its largest volume below the broadest part of the nasals, where the ossification of the upper ethmoid at present ends. A section at this part (Plate X. fig. 19) shows a very unexpected richness of cartilaginous outgrowth, such as is seen in no other known bird, the Emu making the nearest approach to it. The septum nasi (*s.n.*) is rather thick at this part, very swollen below, where the trabeculæ lay, and somewhat thickened also in the middle; above it gives off its alæ (*al.s.*), which rise in a rounded manner, and then curve downwards and outwards. At a line from the mid line the alar lamella splits, the outer plate being moderately convex in section, and forming the cartilaginous nasal wall, whilst the inner plate curves abruptly inwards, forms nearly a semicircle, and then begins to give off secondary and tertiary lamellæ (*i.t.b.*). There are twenty of these folds on each side, nearly a third more than in the Emu, but formed after the same fashion, some of them being single (secondary), and some double and even treble (tertiary lamellæ). The outer nasal wall passes below the inferior turbinal folds, and ends behind in a curious thick blunt hook (Plate X. figs. 18 & 19, & Plate XIV. figs. 1 & 7, *a.i.t.*), on the convexity of which the base of the antorbital plate of the lacrymal rests, and which ends externally inside the zygomatic process of the prevomer (*p.v.*). Both behind and in front (Plate X. fig. 18) the turbinal folds become simpler; but they reach nearly to the anterior nasal passage in front, and form a roof to the middle nares behind. There is therefore no special turbinal to the alinasal cartilage, as there is no actual boundary line between these two regions. This makes the alæ nasi look larger than they are (Plate XIV. fig. 1, *al.n.*) actually, and this is one of those most interesting instances of the very *general* nature of the Cassowary. The study of the structures of these vertebrates, in which differentiation or segmentation is imperfectly performed, will be found to be fraught with the richest results to morphology. The anterior nares (*a.na.*) are mere low-lying slits, gradually widening in front; the middle nares (Plate XIV. fig. 2, *m.na.*) are large, suboval, and perfectly struthious, being greatly severed by the intrusion of the over-large vomer (*v.*). The curious inferior turbinal hook is the continuous homologue of the distinct lower antorbital piece of certain birds, *e. g.* "Musophaginæ," "Larinæ," "Procellarinæ," &c.

The visceral rays are very variously developed as usual, the first prestomal being never other than continuous with the skull base; and already at this stage the anterior (prenasal) half has waned into a mere thread.

The posterior half of the *larval* intermaxillary is the thick swollen base of the internasal cartilaginous plate (Plate X. fig. 19, *s.n.*); and there is never any line of distinction between this wall, which, as a continuation of the ethmo-presphenoidal cartilage divides one nasal labyrinth from the other, and the double (trabecular) foundation on which it rests. The primordial part of the palatine apparatus—the second pair of prestomal bars—is as simple as usual, there being only the palatine and pterygoid (Plate XIV. fig. 2, *pa.*, *pg.*) bones, answering to the pier of the arch only. The former is almost horizontal; the inner proximal edge, the anterior point of which is attached to its true basis (the lateral ethmoid), lying a little higher than the thick outer edge of the bone. The oblique sutural line between the palatine and pterygoid is of great extent, the former bone passing nearly to the end of the latter, this bone (the pterygoid) also running along the whole inner margin of the palatine. Anteriorly the external margin of the palatine fits, by harmony, with the inner edge of the prevomer (*p.v.*), this almost confused interlocking of primary with secondary bones being a constant thing in the structure of the facial arches. The front edge of the broad part of the palatine, bounding the middle nasal opening, is sharp and toothed; the external margin of the bone is sinuous, the front spur turning inwards, whilst that which clamps the pterygoid curves a little outwards; below, the broad part of the bone is scooped, making the middle nostril deeper. The pterygoids have their usual struthious form, being thick behind, where the quadrate and sphenoidal facets are placed, and thin and splintery in front, where the "mesopterygoid" becomes segmented off in other birds. The great visceral arch, the first poststomal or mandibular, has nothing very remarkable about its primordial structures; this is to be said, however, that the quadrate (Plate XIV. figs. 1–3, *q.*) is not so cumbrous a bone as in the Emu, the metapterygoid process (not quite ossified) being rounder and smaller; the oblong upper condyle stands on a longer neck than is usual, and the body of the bone is more compressed from before backwards; there is already a wind-passage in the flat hinder face of this bone (Plate XIV. fig. 2, *q.*). Ossification has commenced in the articular head of MECKEL'S cartilage (Plate XIV. fig. 4, *ar.*), which has scarcely begun to shrink anteriorly, although nearly buried in the splints.

The broadly triangular, deeply lancinate (or rather *runcinate*) tongue has in its substance the lower part of the second pair of poststomal rays; these are coalesced at the mid line, and together are like a thick heart-shaped leaf (Plate XIV. fig. 12, *c.h.*). The basal cartilage (*b.h.*), thick in the middle and bluntly pointed at both ends, fits in front into the notch made by the posterior divergence of the flat "cornua minora." The lower thyro-hyal (*th.* 1) is considerably ossified, the upper piece (*th.* 2), the cerato-hyals, and the combined basi- and uro-hyals (*bh.*, *uh.*) not at all; the whole structure agrees closely with the like parts in the Emu.

There is nothing especial in the auditory "columella" (Plate XIV. fig. 2, *st.*), which agrees with that of the Emu.

There is very much that is of interest in the splint-system of bones in the Mooruk's skull. There is very little trace of the posterior fontanelle (Plate XIV. fig. 4), for the superoccipital has already fitted into the very obtuse angle formed by the meeting of the parietals behind; the anterior fontanelle (*fo.*) is lozenge-shaped, and is 2 lines across. The squarish parietals (*p.*) are becoming thick, and are already considerably scooped to form the temporal fossæ; they are very curved, for the skull is *high*, as in the Emu. The frontals are still higher, are becoming thick, but are very squamous behind; at the mid line (Plate XIV. figs. 1–8, *f.*) they are cut off from much of their territory by the uprising of the overgrown ethmoid; so they are mere styles in front and lie under the edge of the broad ethmoid, and wedge themselves in between and below the lacrymals and nasals (Plate XIV. fig. 7). The orbital plate of the frontal is for the most part only 2 lines in breadth, but it is sending a long pointed lamella to be strapped to the side of its proper primordial pattern—the orbito-sphenoid (Plate XIV. figs. 1 & 14, *f.*, *os.*). The lacrymals (*l.*)—the splints that apply themselves with exceeding closeness to the lateral ethmoidal region (Plate X. fig. 19, & Plate XIV. fig. 7)—are very large, as in most of the Ostrich-group; they send a long process to supply the place of the absent superorbitals; and apply themselves by a very long harmony-suture to the still larger nasals; the antorbital plate of the lacrymal is thicker than usual, has no fenestra, and is somewhat pedate below (Plate X. fig. 18, & Plate XIV. fig. 7). The nasals are very peculiar, if compared with those of the purer types of birds; they come nearest those of the Rhea as to their mutual approach at the mid line, and to those of the Great Ostrich in the size of the very ornithic descending process (Plate XIV. figs. 1 & 3, *n.*). Yet this process is very feeble; and on the whole the nasals of the Cassowary are an exaggeration of what is seen in the other "Struthionidæ," even in those very characters which are especially struthious. Behind, they reach to the very middle of the superorbital region, are there mere thick styles widely thrust apart, like the half-open blades of a pair of scissors; but they become very broad and massive between the body of the lacrymals, and where they have met in front of the narrow end of the exposed upper ethmoid. Even in this young specimen the nasals lie together for one-third of an inch, and then, for the same distance, gently diverge to let in the feeble, coalesced nasal part of the intermaxillaries (Plate XIV. fig. 3). The descending crus of the nasal is a small style, which lies obliquely in front of the exposed upper part of the lacrymal; it does not reach the gooseberry-prickle-shaped ascending process of the prevomer (Plate XIV. fig. 1, *p.v.*). The posterior nasal blades are scooped; the thick part has large pores; the anterior narrower part is strongly convex, each bone fitting itself on to its own primordial mould or pattern, *e. g.* the arched wings that give off the rich inferior turbinal outgrowth. Although the nasal be a mere splint—an "aliseptal operculum"—yet its development and modification are of great interest to the morphologist. I shall therefore, in this case, anticipate my future papers, and compare this part of the Cassowary's head with that of another of the "Grallæ," indeed, but with one which ranks above most of that heterogeneous "Order," viz. with the "Aves Altrices." The common Heron (*Ardea cinerea*) shows to what *typical* height a wading bird may attain, and I am fortunate in possessing the skull of a fledgling*.

The whole length of this skull is 5 inches 9 lines, and yet the intermaxillaries, measured along the nasal processes, are 4 inches 2 lines in length; the solid part is 9½ lines in extent, and the dentary margin, to the end of the angle, 2 inches 10 lines. The entire length of the nasals is 3½ inches; their hinder part is broad, flat, splintery, and pointed at the extreme end; at the broadest part they meet within half a line; but the very delicate styloid ends of the intermaxillaries can be seen between them, lying on an acutely-angular space between the frontals, and showing a trace of the ethmoid.

The nasals in front of the lacrymals divide, the upper crus, wholly separated from its fellow, becoming gradually an extremely delicate style, which runs up to the solid part of the intermaxillary. The lower crus of the nasal is thick, descends obliquely forwards, lies on the prevomer, and has the flat fibrous angle of the intermaxillary clamping its outside. The suture between the nasal processes of the intermaxillaries can be traced nearly forwards to the solid part of the bone, viz. for 3 inches 3 lines. The prevomers reach within an inch of the end of the beak in front, and within 4 lines of the quadrate bone behind; they are 3 inches 8 lines in fore-and-aft extent; the whole extent of the intermaxillary apparatus being 4 inches 9 lines, one inch less than the length of the whole skull and face. This disproportion of the intermaxillary apparatus becomes still more inordinate in the adult bird, and much more extraordinary measurements could be given from the skulls of the "Ibidinæ" and "Tringinæ."

The nasal processes of the intermaxillaries (Plate XIV. figs. 1 & 3, *px.*) in this young Mooruk are less than half an inch long, one-seventh the length of those of the young Heron, a bird not much more advanced in development, and of a smaller size. In the Ouaran Lizard (*Psammosaurus scincus*), a species of Monitor, the single process of the azygous intermaxillary cleaves the azygous nasal; this styliform compressed process is longer than its counterpart in the young Mooruk. Amongst the mammals the "Leporidæ" have the largest intermaxillaries (if we except the Cetacea, Monotremata, &c.); but the long process which each bone gives off, to pass upwards and be let into the frontal, is *outside* the broad turbinated nasal. Altogether the Cassowaries have the smallest intermaxillaries, not excepting even the "Fissirostral" birds, *e. g. Caprimulgus*, *Cypselus*, &c. The marginal grooves are well shown on the body of the intermaxillary of the young Mooruk. They have their counterparts in the dentary rami (Plate XIV. fig. 1, *p.x.*, *d.*). Beneath, the canal which contains the remnant of the prenasal cartilage is well marked (Plate XIV. fig. 3, *p.x.*); behind that canal the bone is double on each side; the thick styloid dentary process running outside to the base of the lacrymal, and the flat palatine process (mesiad) running back to the broadest part of the vomer, and becoming notched towards the end.

---

* This bird, although ready to fly, had not left its *elevated* cradle; it was from the heronry in Milton Park, Northamptonshire, on the estate of Earl FITZWILLIAM.

The prevomer (Plate XIV. *p.v.*) is well developed; anteriorly it reaches further forwards than the long vomer, and within 5 lines of the end of the upper bill; it is 1 inch 4 lines long, a line longer than the vomer. This middle intermaxillary splint appears on the zygomatic margin of the cheek for 5 lines; there is no maxillary to hide it, but the jugal overlaps it for some distance. Externally, in front, a long styloid process fits into that notch in the intermaxillary which should be the "anterior palatine foramen;" behind this it widens inwards to join the broad part of the vomer (one of its most essential and primary connexions), then for half an inch it is scarcely 1½ line wide, and, notched behind, it gives off a short spur to join the palatine, and a longer one to fit to the jugal (Plate XIV. figs. 1 & 3, *p.v.*).

The ascending process—that which gives the bone its thoroughly ophidian character—is much like that of the Rhea (Plate XIV. fig. 1, *p.v.*); it is triangular, and curved backwards at its blunt point: the point needed to be but a little sharper to have made this process, with its broad basis, a very near counterpart, in form, of the prickle (*aculeus*) of the gooseberry-bush. It is worthy of notice how the over-development of the three almost equal intermaxillary splints has in these birds sufficed to wall-in the soft nose-labyrinth in the absence of the great, usual, maxillary splint. This latter bone is badly developed (above) in Snakes and Monitor-Lizards, and is a frail sieve of bony openwork, strengthened above by a strong oblique beam from the intermaxillary, in Hares and Rabbits (*Lepus*), creatures rich in *oviparous* characters.

The vomer of the Mooruk (Plate X. figs. 18 & 19, & Plate XIV. fig. 3, *v.*) is of great length, and is also very broad at the anterior part—that part which answers to the lower portion of the bone in the Chelonian; it is very much split at both ends, especially behind, and, as may be seen also in the adult common Cassowary, the bone is like two pieces conjoined by a long isthmus in the middle.

Anteriorly the vomer underlies the septum nasi, then two-thirds of the rostrum of the basisphenoid (Plate XIV. fig. 7, *r.b.s.*, *v.*); and its hinder lobes are strongly fitted beneath each "mesopterygoid" spur of the pterygoids (Plate XIV. fig. 3, *v. pg.*). So that Nature has very carefully builded the bird's skull, laying balk upon balk; first the rafters (trabeculæ) grew together, and made the strong beam-like basis of the orbito-nasal partition-wall; then the pituitary floor grew forwards, first as cartilage and then as a bony rostrum beneath this beam, fitting in a groove-and-tongue manner most accurately, the groove being in the " rostrum " and the tongue on the " septum ;" and then these became strongly undergirt by the bony semicylindrical vomer. Moreover, behind the vomer, the middle (sphenoidal) balk grows out on each side in the form of strong spurs, which stretch across to the pterygoid like a roof-collar or wind-beam. This very safe kind of building is best seen in these " Struthionidæ," for in other birds the cross-bars, or the lower beam, or both, may be deficient; the vomer being very variable, and the anterior pterygoid processes soon becoming arrested in many genera and families.

In this Cassowary we see but a poor remnant of the second prestomal splints, the inner pair being absent, the first outer pair mere flattened styles—the jugals (Plate XIV. figs. 1, 2, 3, *j.*); whilst the second, the quadrato-jugals (*q.j.*), are very small addenda to the jugals, just serving to connect the zygomata to the quadrate bones. Moreover, as we have seen, these splints are thrust away from their early-ossifying primordial bars by the intrusion of the huge middle splints (prevomers) of the first prestomal arcade.

The squamosals of the Struthionidæ all speak one language, but in none are the utterances so distinct as in the case of the Cassowary. If the reader will refer to Professor HUXLEY's new work on Anatomy, and compare fig. 65, *Pr.Op.* p. 162, fig. 84, *F.* p. 208, and fig. 86, *C.z.* p. 214, with the squamosal of the young Mooruk, he will see at one glance a complete harmony of the " preoperculum " of the Fish, the temporal " operculum " of the Lepidosiren, the " temporo-mastoid " of the Frog, and the squamosal of the air-breathing Vertebrata. As to the Frog and the Mooruk, the shape of the bone has merely to vary from that of a hammer to that of a hatchet, and the oneness is absolute. But it is not on the accident of shape that I would rely to prove this identification, but on the history of the development of the bone, viz., as a splint upon the quadrate pedicel of the mandibular ray, whether that pedicel be segmented from the periotic capsule and " investing mass," or whether it be continuous with it*.

The mandibular splints have their usual development, the dentary (Plate XIV. fig. 1, *d.*) being the longest, and the splenial the next in size, then the surangular (*s.a.*), whilst the angular (*a.*) and the coronoid are nearly of the same size. The pinched face of the Cassowary makes the mandibles to be much like those of the Tinamou, the rami meeting at a very acute angle, and the dentaries being narrow feeble bones. If these mandibular splints were during growth to become as free of the primary ray as those of the palato-maxillary region, we should have essentially what occurs in the inner and outer splints of the huge hyoid arches of the osseous fish.

I have studied the structure of the skull in the adult condition both of the common species (*H. galeatus*) and also of the Mooruk (*C. Bennettii*), but my space will not serve to trace the changes, which are similar to those that take place in the other " Struthionidæ ; " the description above given of the chick will serve the student as a guide in his interpretation of the fully developed skull.

---

* The supposed " squamosal" of the Fish does not stand in the way now (see HUXLEY, *op. cit.* p. 188). CUVIER and OWEN made the nearest guess as to its nature.

Dinornis robustus.

No specimens of the skulls of young individuals of the Dinornis have come under my notice, only sternal and pelvic bones; I have, however, some remarks to make upon the adult skull of the subextinct form. I have studied the skull of *Dinornis robustus* both in the specimens contained in the British Museum, and also in Professor HYRTL's fine skeleton *.

But the freshest and most perfect skeleton and skull of this bird has been recently added to the York Museum; and some of the bones, both young and old, were exhibited and described by THOMAS ALLIS, Esq., F.L.S., at a Meeting of the Linnean Society, June 16th, 1864. Tendon, cartilage, skin, and even feathers still adhered to these precious bones, the dried articular cartilage having the amber-coloured tint seen in the bones of creatures not long dead. The skull was not exhibited at that Meeting, but my friend H. B. BRADY, Esq. (well known as a Rhizopodist) has kindly supplied me with the three very beautiful photographs of these *fresh* bones of the Moa, published by MONKHOUSE and Co. 4to. Lendal, York.

One of these gives an obliquely lateral view of the skull and mandible, and on another sheet there is a basal view of the skull, and an upper view of the coalesced mandibles. All the York specimens were taken out of the same sand-dune in New Zealand, both young and old, the young ones having the sternum in two distinct halves, and the pelvis in distinct pieces; the ilium quite detached, the ischium and pubis undergoing anchylosis. These *chickens* must have been nearly twice the bulk of a large Turkey. The skull of the adult is beautifully displayed in these photographs, is nearly perfect, and the relations of this bird to the other "Struthionidæ" can be clearly read off in the light of what has been given above, in my account of the early skulls of the well-known living types. It may be well to remark, in passing, that the pelvis of *Dinornis robustus* answers to the simple type of that of the Apteryx, Cassowary, Emu, and Tinamou; whilst the sternum reminds the observer both of that of *Struthio* and of *Apteryx*. Besides characters of its own, the skull has those of the African Ostrich and of the Emu; we have seen that the Ostrich comes between the Emu and the Rhea: the relations of the whole group are very interwoven.

The robustness of the skeleton generally is not wanting in the skull, every part showing a solidity, a breadth, and a depth very unlike what is seen in the largest and strongest of the well-known living forms; and ossification has gone on to a higher degree than is usual in this family of birds, and more like what occurs in the Rails. It would be difficult to find two skulls in more perfect contrast with each other than that of *Dinornis robustus* and of the so-called *Dinornis casuarinus* (Trans. Zool. Soc. vol. iii. pls. 52 & 53, p. 348), the latter being in reality a Notornis†. It will save trouble in the comparison of these forms if the latter bird is put at once into its own group; its specific name may stand, but I shall take the liberty, for the present at least, to speak of this huge Rail as *Notornis casuarinus*. In the Dinornis (see the photographs mentioned above) the occipital condyle is sessile, transversely oval, and deeply dimpled; in the great Notornis this condyle is elegantly hemispherical, strongly pedunculated, and has the dimple obsolete. In the Dinornis, as in the other Ostriches, the basioccipital is deeply scooped in front of the condyle below, and then becomes very tumid; in the Notornis there is one continuous concavity along the mid line, from the condyle to the front of the basitemporals; whilst each side of the bone gives off a strong keel where it joins with the down-turned edges of the exoccipitals; thus we get the most perfect counterpart of the basioccipital region of the "Delphinidæ." In the Dinornis the foramen magnum is subcircular; in the large Notornis it is oblong, being very high, and having almost straight sides. The exoccipitals of the Dinornis are very shallow, and help to form the tympanic cavity to a small extent only; the reverse of this is the case in the Notornis. In the Dinornis the basitemporals are small and entirely lateral; and in this photograph, in which the skull is given in a figure only 16 lines in length, a remnant of the posterior basicranial fontanelle can be seen, and this presupposes the absence of the secondary floor at that part. In the gigantic Notornis the basitemporals have their highest development. I had already noticed the extreme thickness of the combined basitemporal mass in the little native Corn-crake (*Crex pratensis*), and then in that connecting link between the Rails and Cranes, the Trumpeter (*Psophia crepitans*), and was therefore prepared to see a large outgrowing mass in this region in a gigantic form of the Rail-type. The outgrowing wings (pterygoid processes) of the basioccipital are repeated again in the basitemporals; and here, in this Giant Rail, they attain the largest size ever seen in the bird-class; next to this bird, in this respect comes the King Vulture (*Sarcorhamphus papa*), and next to that the Palamedea (*Chauna chavaria*); but in the latter the basitemporal mass, which is extremely thick, is developed most from side to side.

---

* In the International Exhibition of 1862.

† Being anxious to know whether the eminent author of the paper above referred to had changed his view as to the nature of the pickaxe-headed bird since 1848, I referred to the well-known recent work of his (OWEN, Palæontology, 2nd edit. 1861, pp. 330–31). In that work the species of his genus *Palapteryx* are, with

Now we saw that, in respect of the basitemporals, the Cassowary came nearest to the ordinary Mammalia; and the Dinornis is a casuarine Ostrich. This Great Rail, on the other hand, like the King Vulture and the Palamedea, has retained the basitemporal pterygoid processes of the Lizard. Now in the Lacertilia there is the merest shadow of the basisphenoidal "rostrum"; and in *Notornis casuarinus* it has about the smallest relative development of any bird that I am acquainted with—far smaller than in the other members of the Rail-tribe.

---

great judgment, all merged in the genus *Dinornis*; the species are thus very numerous, viz., *D. elephantopus, giganteus, ingens, struthioïdes, rheïdes, dromioïdes, casuarinus, robustus, crassus, geranoïdes*, and *curtus*. Here is *D. casuarinus* in the very midst of ten struthious species, and yet as long ago as 1848 Professor OWEN well knew that the skull which he described under that name did not belong to a struthious bird.

It is but just to remark that the author had some doubts on his mind (see Zool. Trans. vol. iii. pt. 5, pp. 350 & 376) as to this matter; and one would be glad to know whether the term *casuarinus* has been applied by him to some really struthious fossil, the adze-headed bird being left out of the question.

We have shown that this rostrum attains its extremest size in the "Struthionidæ;" and amongst them it is largest in the African Ostrich. *Dinornis robustus* agrees entirely with the African bird in this respect, as the photograph beautifully shows, for the lower table of the bone is broken towards the base, and the coarse diploë can be seen within; in front of this abrasion the rostrum is seen swelling out into an enormous basiseptal beam, exactly as in *Struthio camelus*. At the base of the rostrum, in front of the basitemporals, the great anterior pterygoid processes are given off in the Dinornis; they extend further outwards than the basitemporals, as in all the Struthionidæ, and in no other birds. These processes are aborted in all the Rails, a mere trace being visible in some of them, as in the Crake; they are quite aborted in the Notornis, and they exist in no known Reptile; but they reappear in some Mammals, e. g., *Cavia*. In all the "Struthionidæ" the body of the basisphenoid intervenes (below) between the openings of the Eustachian tubes; in all other birds the basitemporals meet below these tubes so as to protect them with a lip-like floor, the tubes opening together close to the mid line; all this is well seen in the Notornis.

When in old birds the Eustachian tubes are at all enclosed in bone, in members of the Ostrich family the sheath is quite lateral, and is formed by the meeting of one lip from the basitemporal, and another from the "posterior pterygoid process;" they evidently have not even this protection in the Dinornis, but, as in the Emu, are only roofed by bone, and are at the widest distance apart. We spoke of both basitemporal and of anterior basisphenoidal outgrowths (wings); they coexist in the Palamedea and the King Vulture, but not in the Great Rail, which thus diverges furthest from the birds towards the Lizards; it had them all, however, in its infancy, for they exist in all embryo-birds.

In *Dinornis* the thick "rostrum" passes forwards to within a short distance of the body of the intermaxillary; in *Notornis* the feeble rostrum is broken off anteriorly; but even if it passed on in front of the vertical ethmoid as far as it does in *Crex*, *Ocydromus*, *Porphyrio*, and *Psophia*, yet it would still be an inch from the body of the intermaxillary. In *Dinornis*, as in the other Ostriches, the perpendicular ethmoid ossifies the whole septum, filling up the space between the large nasal fossæ; in *Notornis* this bone stops abruptly beneath the cranio-facial hinge, in the manner of a typical bird. The posterior wall of the lateral ethmoid is well ossified in *Dinornis*, and has coalesced with the middle bone; these osseous plates extend much further outwards than in *Notornis*.

The os quadratum of *Dinornis* is quite struthious, the upper head not being divided into two heads, the foreshadowings of the incudal crura of the Mammal; and the metapterygoid process is bluntly conical, as in the Emu. In the Giant Notornis this bone is thoroughly ralline, and at the same time perfectly typical. Professor Owen has described it under the term tympanic (*op. cit.* p. 256), and has well shown its peculiarities. It comes very near that of its ralline congeners, especially *Crex*; and the form of its double upper head, convexo-concave, broad metapterygoid process, and pimple-shaped pterygoid process, are all diagnostic characteristics showing its true relationships.

The Ostriches have their pterygoid at its hinder end curled round the front margin of the os quadratum; there is a feebly-marked synovial facet on each bone, concave on the pterygoid, and convex on the quadratum; not so in typical birds, nor in the Notornis. If we look at the bone from below (*op. cit.* pl. 52, figs. 3, 28), we see a small, very high, bluntly cone-shaped process; on this the glenoid cavity at the end of the pterygoid rolls; it is one of the sharpest points of distinction between Ostriches and other birds. Let the observer take the oldest Green Turtle's head (*Chelone mydas*), and although he will not be able to find a distinct metapterygoid process, yet he will find this *pterygoid* process as a blunt style of cartilage; in the dry skull it loses this soft part, and a deep fossa is left.

The point of this cartilaginous projection articulates with the down-turned top of the now sickled-shaped, but once cylindrical "epi-pterygoid" (PARKER; "columella," CUV.); this latter bone, so large and erect in Lizards generally, is a mere transitory epiphysis in the highest types of birds, *e. g.* the Thrushes (*Turdus*), but the cup on its posterior end (= upper in the Lizard) rolls on the knob-like pterygoid process of the os quadratum. My apology for this digression is, that this knob-like process on the os quadratum of the Great Notornis is to the morphologist "a nail fastened in a sure place;" and on it, supposing a mere fragment of this os quadratum had been all we possessed of this bird, might have been hung the full weight of my assertion, viz. that the bird in question is not a congener of the Dinornis*.

The form of the pterygoids is determined by their relations, and can be deduced in both *Dinornis* and *Notornis*; totally different they must have been: in the latter they were slender, and yet short bones, with a deep concavity at the posterior end, and with no facet for the basisphenoid, such as existed in the Dinornis.

The palatines are not shown in the photograph of the Dinornis's skull, but the condition of the surrounding bones show that they were like those of the Emu, and projected but little in front of the suspensorial part. In the Great Notornis each palatine runs 2½ inches in front of the proximal orbital process, and, totally unlike the feeble simple struthious palatine, has the typically ornithic deep groove below, bounded by the two well-marked keels. These palatines, instead of being wide apart, and having a huge vomer separating the two very distinct middle nostrils, are only separated by a space 3 lines wide; in this space (above) lies the tiny vomer, only 8 lines in length, scarcely as large as that of *Porphyrio poliocephalus.* In this vomer the hinder forks are larger than the body, which is slightly split at its apex: in its congeners this end is somewhat clubbed; the vomer is lost from this very fresh *Dinornis robustus* (York specimen). But the prevomer is well seen on one side; and its suture with the intermaxillary and its palatine zygomatic and ascending process are well shown: in the latter (ophidian) process it agrees rather with the Rhea and the Cassowary than with the Emu, or the African Ostrich. The prevomer of the Great Notornis is much broken; but it agrees with the Rails and many other typical birds in the manner in which it projects mesiad of the palatine, as it overlaps it in front of the middle nares. The largest part of the prevomer (the oblique lobe) is broken off in this fossil.

---

* Professor OWEN was perfectly aware of the non-struthious nature of this pickaxe-headed bird; he says (*op. cit.* p. 375), "The Dinornis, if it have no near ally in any known existing bird of New Zealand, appears to have but little immediate affinity to any of the struthious or other known birds in the rest of the world." Now I have compared this skull with those of the genera *Crex, Ocydromus, Tribonyx, Brachypteryx, Rallus, Gallinula, Notornis* (*Mantelli*), *Porphyrio*, and *Fulica*—all true Rails, and with those of the birds that lie in the region round about the Rails, such as *Psophia, Rhinochetus*, &c., and I am perfectly satisfied of its ralline nature. Moreover, now that there are many true struthious heads of the *Dinornis* in the British Museum, how is it that this skull, nearly as precious, and quite as unique as the skeleton of the *Archeopteryx*, is still shown to the public as that of a Dinornis?

But the intermaxillaries of these two types diverge fully as much as any part; the madrepore-like perforateness of the body of the bone shows the place of *Dinornis robustus*; the oblique sparsely-scattered holes in the bone of the Notornis are exactly such as are seen in the smaller *Notornis Mantelli*, in *Porphyrio*, and *Ocydromus*, *Crex*, &c. The lateral grooves, known to every tyro, are well marked in the photographs. They are not present in the Notornis. In one thing these two gigantic forms agree, *e. g.* in the size of the body of the bone; but whilst in the Dinornis it is broadly-outspread, in the *Notornis* it is pinched, decurved, and apiculate. But the nasal process in *Dinornis* only reaches to the lacrymals, stopping in front of the broad ethmoid, and lying loosely over the rest of the face, as in its congeners; in the Notornis it reaches to the same transverse line as the postfrontal spurs, and is sunken into the substance of the skull above, and completely buries the ethmoid. Moreover, this process is thin and lath-like in *Dinornis*; it is a thick slab of bone in the Notornis. The nasals, as far as they are free, are quite struthious; in that family they end in a blunt style; in the Notornis their sutures can be well seen, and they are nearly half an inch wide, where they fit in between the frontals; they are crescentic in this their largest moiety, and curve round behind the nasal process of the intermaxillary, which lies low down between them; for the nasals are more than flush with the top of the frontals. The Dinornis, like the Rhea and Emu (*Dromæus Novæ Hollandiæ*), had scarcely any descending process to the nasal; in the Notornis the fragment of the root of this process shows it to have had precisely the same obliquity as in the ordinary Rails. The frontal region is of extraordinary breadth in *Dinornis robustus*; and the brows are so completely shielded by the outgrowing of the frontals, that the long superorbital process of the lacrymal has melted into the edge of the frontal, a space only being left for the upper part of the small nasal gland. The bony lowering of the brows is seen in other large massive forms, *e. g.* the Dodo (*Didus*), the Adjutant (*Leptoptilus*), and the King Vulture (*Sarcorhamphus*). The edge of the postfrontal is so much produced that the semicircularity of the superorbital rim is lost, and a sinuous and somewhat notched outline results. The whole upper head is one broad, gently convex shield-like mass, shelving down into the extremely wide and rather low occipital region. The temporal fossæ are not so well marked as in *Struthio camelus*, and that notwithstanding the far greater strength of the jaws. The thick, backwardly turned postfrontal is an inch in front of the descending splint-plate of the squamosal, which does not reach so far down the side of the os quadratum as in the ordinary Ostriches. This process is, however, nearly an inch long; in *Struthio camelus* 8 lines, and about 6 lines in the Great Notornis; but in the latter bird there is another osseous tongue an inch in length, and which runs over in front of the os quadratum to within 3 lines of the postfrontal, to which it is connected by an osseous bridge. This supernumerary bar of bone is double in *Porphyrio poliocephalus*, and the front one has connected with it a large ossified mass of the tendon of the temporal muscle.

The large anterior process in the Great Notornis lies so tightly upon the os quadratum, that a synovial gliding joint is formed at that part—a very curious structure. In *Porphyrio* the postfrontal is very short, and does not reach the squamosal spur; old individuals of the Psophia have this long process, which is of tendinous origin. This temporal bridge, which could not have existed if the postfrontal of the Great Notornis had not been of an inordinate size, is the rule in the Gallinaceæ, but is imperfect in *Talegalla*. But this overgrowth of the postfrontal in the Notornis is, as may be seen by the large oblique passages above it, merely a shooting of bone into the dense fibrous tissue of the superciliary region, and extends nearly an inch from the cartilaginous knob on the alisphenoid, which is the true postfrontal. This thick, notched, slit-up mass is ossified separately as distinct bones in the Psophia (half a Rail and half a Crane) and the Tinamous. The temporal fossæ of the Giant Notornis are equally developed with those of *N. Mantelli* and the Porphyrio, almost more so; and very different indeed to their indefiniteness in the strong-headed *Dinornis robustus*, notwithstanding that its jaws are relatively twice as strong as those of the Emu. Undoubtedly the lower jaw of this large Rail, with its pickaxe-shaped upper jaw, monstrously large ossa quadrata, and wide, deep, and well-margined temporal fossæ, must have been very strong; only a little inferior in this respect to that of *Notornis Mantelli*. In Pl. 53, figs. 1, 2, 3, *op. cit.* are given figures of the end of one of the mandibular rami of a large bird; on comparing these with the mandibles of struthious birds and Rails, I find that they agree with the latter; and with none better than the jaw of the little Corn-Crake, *Crex pratensis*. The whole shape of the "articulare," and the manner in which the "coronoid" turns obliquely upwards on the inside of the large open space, thus dividing it into two, these are perfectly ralline, and make it very probable that these are figures of part of the mandible of the Great Rail (*Notornis casuarinus*, Owen, sp.). With regard to the curve of the Great Notornis's bill, I think a few comparisons will make the matter clear. Let the reader put beside this large skull that of *Porphyrio poliocephalus*, and of the semiralline *Psophia*; if one straight line be drawn from the tip of the bill to the end of the zygoma, and another from the commencement of the zygoma to this ideal basal line, he will have the following results, viz. that the vertical line is one-ninth the length of the basal in the Porphyrio, and one-seventh in the other two. The curve downwards in the Great Notornis and in the Psophia is equal, is similar, and in the latter only wants the robustness of the former to make the likeness striking. This accords with the fact that the

Psophia agrees with this huge bird in another point in which the latter diverges from the ordinary Rails, viz. in the perfectness of the interorbital septum.

Professor Owen (*op. cit.* p. 351) was somewhat staggered at finding the sulcus where the coronal suture had been in the Great Rail's skull, "behind the relative position of the persistent coronal suture in the skull of the Palapteryx." A very early stage of the Gallinule's skull explains this; for this and many other water-birds have the parietals very narrow, and the frontals extending far back; whereas the "Struthionidæ," one and all, including the Apteryx, have large broad parietals. The author of the paper quoted above seems to have despaired of finding any near relative for his supposed *Dinornis casuarinus* (see p. 375). I think that its relationships are evident enough, but its "spot is not the spot of the" daughters of the Ostrich.

Yet the predicament in which this huge bird seemed to be placed is really that of the Psophia; for at present we know of no near relative to this bird, which having a truly ralline head set upon the body of a Crane, yet possesses also the superorbital chain of ossicles in common with the struthious Tinamou; this character being borrowed from the Skink-lizards, who borrowed it from the ganoid Fish. Then, curious enough, the Psophia, as we have seen, differs from the Tinamous, the Cranes, and the Rails in having a strongly decurved beak and a perfectly ossified interorbital septum—in this agreeing with the most extraordinary development of the ralline type. Does all this bear upon the morphology of the struthious skull? Certainly; for I have to eliminate the false *Dinornis*, and to put the true typical bird beside the aberrant Ostrich, for comparison's sake: the gigantic Notornis served well for such a comparison. The author of the oft-quoted paper (p. 373) speaks of its "crocodilian cranium;" this may lead to some misconception. This is merely in the thickness of the basal part of the skull; and that is basilateral, and not mesial, as in the Crocodile.

But in the presence of the large basitemporal pterygoid processes, it agrees with the rest of the Rails and the Psophia, and only differs from them in their relative size; and the basal region is relatively quite as thick in *Fulica* and *Crex*. Then the extraordinary development of the tympanic cavities and of the Eustachian tubes in the Crocodile is not in anywise repeated in the Great Notornis, which only differs from the Ostriches, and not from typical birds. There are birds certainly which come near the Crocodile in the upward extension of the tympanic cavities, *e. g.* the Albatros and the "Rapaces," especially the Owls; in these the large diverticula, which pass upwards and inwards, do virtually meet at the mid line through the openness of the diploë which intervenes (at top) between the actual cavities. These extensions upward of the tympanic cavities can be seen distinctly in the "Rallinæ," and a trace can be detected in the Ostrich; but in no known bird is there anything like the Eustachian meatuses of the Crocodile; we might as well look for such pterygoids and such a palatine region as this creature possesses.

There is nothing more characteristic of the struthious bird than the structure of its intermaxillaries and nasals; and the only birds which approach the Ostriches in the loose manner in which the nasal processes of the intermaxillaries fit upon the top of the ethmoid anteriorly, are the Gallinaceæ; the Rails are very different in this respect. The skull of the Gallinule's chick is very instructive, as showing the *typical* condition of these parts; and with this little bird the extinct gigantic form agrees in all essentials. In the young Gallinule (about five weeks old) the nasal processes of the intermaxillaries are already quite confluent; and both together form a relatively large bar of bone, the exact counterpart of that of the gigantic form. But the whole of this bar is not to be seen from above, for it enters, almost undiminished in size, beneath the broad posterior part of the nasals, which form the front half of the superorbital region, from side to side. These broad plates still further hide the nasal part of the intermaxillary by each sending forwards a rounded lobe, the two lobes thus increasing the roof over this bar. The upper view of the skull of the Great Notornis shows this hiding of the posterior part of the intermaxillary, but not to the same degree; indeed this structure may be seen in many water-birds, *e. g.* the "Lamellirostres," especially the Palamedea and the Mute Swan; but in these the nasal part of the intermaxillaries is very slender, and the mesial suture is persistent.

Palapteryx.

The same valuable paper (plates 54 & 55, p. 360) contains figures and descriptions of the remains of some true struthious birds, under the generic term *Palapteryx*. I must refer the reader to the paper itself for the descriptions, reminding him that the nomenclature of the bony parts is very different from that which I am in the habit of using; *e. g.* Professor OWEN'S "mastoid" is my squamosal; his squamosal is here called "quadrato-jugal," and his "tympanic" "os quadratum," besides several others. I have carefully examined the original specimens, as well as the drawings in Professor OWEN'S paper, and I am quite of opinion that the somewhat unfortunate generic term *Palapteryx*—which would seem to indicate that this is the more generalized and ancient form of *Apteryx*—has been very properly dropped, as the birds were evidently, to all intents and purposes, only specifically distinct from the largest forms of *Dinornis.*

The beautiful photographs of *D. robustus* show that the solid part of the intermaxillary was unusually long and large, and that it was more decurved than is usual in the group; yet the differences between these extinct congeners of the Emu were not much greater than may be seen between *Dromæus irroratus* and *D. Novæ Hollandiæ.* The profile figure of *Palapteryx geranöides*? shows the intermaxillary too far removed from the skull, and thus giving the appearance of a longer head than that bird really possessed (see plate 54, fig. 1, *op. cit.*). The height and strength of the upper and lower jaws of this bird are somewhat remarkable for one of the "Struthionidæ," but *Dromæus irroratus* connects it with the feebler-faced *D. Novæ Hollandiæ.* The basal figure (fig. 3) beautifully displays the characters of the true Dinornis; and there is a remnant of the pituitary space, showing that the basitemporals were lateral, as in all the group. Like *Dinornis robustus*, the basisphenoidal "rostrum" swells out as it passes forwards; thus showing the relationship to the African type, which, as I have already related, is also strengthened by the condition of the sternum in *D. robustus.* It is extremely probable that at no far distant period New Zealand was inhabited by a large number of species of *Dinornis*, some of which may have had differences such as would, if we knew them, enable us to make some subgenera out of this group. Perhaps, at present, *Palapteryx* had better hold the smaller kinds, in a subgeneric way, and the largest kinds be called *Dinornis*; as for the so-called *D. casuarinus*, let it wheel off to its own phalanx, and take rank as the chief of the Rails.

Apteryx australis.

Not possessing any materials for working out the development of the young *Apteryx*, I must refer the reader to M. Blanchard's very valuable work, 'L'Organisation du Règne Animal,' 20^{e} Livraison, Oiseaux, Livraison 1re.

The two plates given in this first Number, on the Birds, are from drawings made by M. Blanchard himself, of the osteology of a young individual of *Apteryx australis*; they are exquisitely drawn and engraved, and are of the highest interest and value.

As I am able to compare these plates with the large series of young struthious skulls already described, and also with an almost indefinite number of growing skulls of the more typical species of land- and water-birds (in some cases of very many stages of the same species), I think that such a comparison will not be devoid of value. I must also refer the reader to Professor Owen's invaluable contributions on this subject (see Zool. Trans. vol. ii., and Osteol. Catalogue Mus. Coll. Surg. vol. i. p. 250. No. 1355*). M. Blanchard's figure of the basal view of the skull (plate 2, fig. 2) does not give us anything that is new, for in this region coalescence of the parts in this young individual had already obliterated most of the sutures. The perfect struthiousness of the bird is, however, well shown; and the articulation of the large, distinct, flat posterior crura of the vomer can be seen articulating with the splint-like anterior part of the pterygoid, to the outer side of which bone the palatines have become anchylosed. The converging ridges that meet at the root of the basisphenoidal "rostrum," one from each basitemporal, join a keel which runs forwards under the rostrum, and backwards halfway to the basioccipital. The "rostrum" is subcarinate in the round-headed *Dromæus irroratus*, so different from *Struthio*, *Dinornis*, and *Rhea* in this respect. On each side, where the vomer becomes solid, the palatine can be seen articulating with the palatine process of the long intermaxillary. The transverse occipital condyle, the continuous head of the "os quadratum," and the very shallow drum-cavity, with its perforate roof and thick obtuse exoccipital back-wall, are well shown in fig. 2.

---

* There are some remarkable errors in this otherwise valuable abstract of Professor Owen's larger paper on the Apteryx; *e. g.* the "Ibis" referred to is not an Ibis at all, but one of the long-billed "Tringinæ" (see also p. 242. No. 1293); then the pterygoid processes in the Lacertine *Sauria* grow out of the basitemporals, and not out of the basisphenoid, which is aborted in them; lastly, the counterparts of the anterior pterygoid processes of the "Struthionidæ" exist in the embryo of all birds, and are developed in about two-fifths of the genera.

The lateral view (fig. 3) shows that the frontal had not coalesced with the parietal above, nor with the alisphenoid below; and also its distinctness from the nasal and antorbito-lacrymal mass anteriorly.

The gentle manner in which the occipital region graduates into the parietal is well shown in this figure (3), reminding the observer of the skulls of the Echidna, Mole, and Shrew; we also see the similar graduation of the skull into the face. The squamosal has united with the lower edge of the parietal; it binds the os quadratum strongly, with its large descending process, as in the other " Struthionidæ." The anterior sphenoid is of small extent, the " rostrum " is distinct from its base, but both base and alæ are completely confluent with the largely developed lateral ethmoids. These plates are very large and swollen; the upper, answering to the cribriform plate and back of the upper turbinal, the lower part to the pars plana, or back of the middle turbinal. There is a large notch in the lower edge of the orbital plate of the frontal; but this is made into a large irregular foramen by the immediate contiguity of the upper edge of the simple cribriform plate; this is the " upper orbital fontanelle;" and at this part the olfactory crus is only protected externally by membrane. There is no such open space in the skull of the adult African Ostrich, and in the Rhea it is only large enough to allow the olfactory crus to escape into the orbit, along which it passes to gain the *non*-cribriform chink between the vertical ethmoid and its ala. In the Tinamou (*Tinamus robustus* and *variegatus*) the broad end of this fontanelle and the olfactory chink are half an inch apart at the top of the large orbit. The postfrontal part of the alisphenoid is not developed, and the feeble postorbital process of the frontal does not come near that part of the skull; this is similar to what is seen in the Mole. The tumid "pars plana" projects outwards to anchylose with the inner edge of the lacrymal, which has the usual fenestra, but is very small, and is shorn of its superorbital part; moreover the large lateral development of the ethmoid has pushed up against the descending crus of the nasal, another unique character for a bird.

The middle plate of the ethmoid is not differentiated from the septum nasi, which has a fenestra behind, between the fullest part of the inferior turbinals. The metapterygoid process of the os quadratum is seen to be obtusely conical, as in the Emu, the quadrato-jugal to be much longer than is usual in the " Struthionidæ," the malar to be of the ordinary size, and the zygomatic process of the prevomer to reach nearly halfway along the zygoma.

With the skulls of two species of Tinamou before me, I am able to decipher the structure of the nasal of the Apteryx; for, as in those birds, it has a descending bar to this bone, which, as in them, thickens as it descends obliquely forwards, and is pedate below; behind, and within it, there is evidently a slight upgrowth of the prevomer (the ophidian process), such as I shall soon describe in the Tinamou.

The end view of the Apteryx's skull (pl. 2. fig. 3) shows the roundness of the crown, the great width of the occiput (unique in being the widest part of the skull), the transverse character (not hemispherical) of the occipital condyle, the projection, so smooth and round (as in the Mole) of the superoccipital plate, and the persistence of the middle part of the lambdoidal suture.

Perhaps the most interesting part of these illustrations is the upper view (pl. 2. fig. 1), for here are to be seen the greatest number of sutures.

Only the middle third of the lambdoidal is to be seen; but the sagittal and the coronoid are completely open, and show their teeth well. The parietals are aberrantly large, as in the other "Struthionidæ;" but the frontals, defrauded behind, are projected further forwards than in typical birds, on account of the diminished size of the posterior part of the nasals. An oval space, more than a line in length, appears in the parietal part of the sagittal suture, nearer the coronal than the lambdoidal suture. This is the famous *lacertian* "parietal fontanelle," which in the Apteryx appears for a little time and then vanishes away. Even in the dense skull of the Blind-worm (*Anguis fragilis*) this space will not fill up, but is a notable oval neat hole, and its constancy in the Lacertilia is not a little remarkable. In examining the skull of an extremely young Gecko*, I find that the great anterior fontanelle is lozenge-shaped, and that the posterior angle is rounded (and the same condition is to be seen in *Hæmatopus* during the first summer); this becomes the remnant of the originally large space which does not fill up. Now there are certain groups of birds which approach the Reptiles evidently, but not the Mammalia as well, as we see in the Ostrich-tribe; amongst these are the "Lamellirostres," from the hen-faced, free-toed Palamedeass, to the most perfectly-toothed of living feathered types—the Goosanders (*Merganser*). The semi-terrestrial species scarcely hide the fore paw in the wing; these are the Geese and the Screamers (*Palamedea*, *Chauna*). Now in the Geese and Swans the "parietal fontanelle" of the Lizard reappears, and is often persistent; for in very old individuals the anterior fontanelle is badly filled up. In the oldest and densest common Goose's skull in my possession three of the angles of the original lozenge are still open, the posterior of these being the counterpart of that in the adult Lizard. In the Common Duck (*Anas boschas*) this structure may be seen during the first summer; it then fills up. The upper view (fig. 1) of the Apteryx's skull shows well the extension forwards of the parietals, and consequent shortening of the frontals, which, however, are themselves developed much more anteriorly than in other birds; for, as in the other Ostriches, the nasals of the Apteryx are but narrow behind, and the exposed portion of the ethmoid is only moderate, as in the Rhea. The long nasal part of the intermaxillaries, as is usual in the tribe, ends in front of the lacrymal; but this is not unlike what is seen in those simpler types of the "Grallæ" which have, like the Apteryx, long bills, e. g. *Tringa*, *Limosa*, *Numenius*, *Hæmatopus*. In most of these, these processes are very delicate, and pointed towards the end; but in the *Hæmatopus ostralegus* each moiety (in the young bird) ends separately in a flat lath-like flap; this divergence of these intermaxillary rami, with a rather persistent separateness, and their flat condition, is exactly like what is shown in this figure of the Apteryx. This leaning, as it were, to the simple, but thoroughly differentiated and typical "Grallæ" is extremely interesting, because in the next subgroup (the Tinamous) the characters of special types begin to break out and to become unmistakeable; so that these birds seem to have something mixed and monstrous in them, a very patchwork of ornithic qualities. The nasal processes of the intermaxillaries of the Apteryx continue distinct (at this stage) for an inch; combined, they form a strong bar more than 3 lines thick; then the solid part is extremely short, and being deeply grooved, looks as though the nostrils were subterminal; the nasals flank the nasal processes of the intermaxillaries for nearly half their length posteriorly. The angle of the dentary plate of each intermaxillary reaches two lines further backwards than the nasal process.

---

* A *Hemidactylus*, from Barbadoes.

Plate 2, figs. 3 & 5, show the five usual splints and the "articulare;" the symphysis is three-fifths the length of the mandibles; and the splenial pieces, which are 3 inches long, have nearly half their length in front of the divergence of the rami.

The os hyoides (pl. 2. fig. 8) agrees with what I have described in the Emu and Cassowary, viz. a basi-uro-hyal piece pointed at both ends, and a two-jointed pair of first branchials; but the flattened cerato-hyals are not shown in this figure.

In the descriptions that follow I shall make use of these observations upon the skull of the young Apteryx; and a comparison of the Tinamous with the other "Struthionidæ," without the Apteryx, would have been very imperfect. Of all known birds, the Apteryx and the Cassowary appear to me to be least ornithic and most generalized; the leaning of the latter is evidently most to the Gallinaceæ, that of the former to the long-billed "Pluvialinæ;" but the Cassowary and the Apteryx seem to approach equally near to the Mammal on one hand, and to the Reptile on the other.

Tinamus variegatus and *robustus*.

I have in another place (Zool. Trans. vol. v.) described the skull of *Tinamus robustus*, but there are points of its structure which must be described here, in comparison with that of *T. variegatus*. In the paper just referred to I have given at length my reasons for placing these birds with the "Struthionidæ;" we shall find as we proceed that whatever tendencies to affinity with other groups may be discerned in the larger Ostriches, yet these declarations for special types are but feebly uttered, when compared with what is manifested in the "Tinaminæ." The Fowl and the Plover strive for mastery here, but the nature of the bird has to be drained through several generic "limbecks" before it becomes pure and simple enough to be truly gallinaceous or truly pluvialine; the Sandgrouse and the Hemipods, and even the Megapods, all intervene between the evidently heterogeneous Tinamou and the true Fowl and Plover*.

The first point to be noticed in the Tinamou, the occipital condyle (Plate XV. fig. 2, *oc.*), is a departure from what we have seen in the "Struthionidæ;" and although this bird comes so near the "Gallinæ," which have this knob bifid, yet in the Tinamous it is oval longitudinally, being an exaggeration of what exists in the Rails and even in Plovers. The thick basal region of the skull (*b.o.*, *b.s.*) is gently convex, and in *T. robustus* is also slightly carinate anteriorly; there are indeed four carinæ, as in the Apteryx, the longitudinal ridge being broken at the base of the rostrum, by a remnant of the pituitary space (see Zool. Trans. vol. v. pl. 40, fig. 1, in which figure the converging lateral ridges might be mistaken for the edges of the basitemporals, which in typical birds do meet at that point). The eustachian canals are floored by bone for a very small space, and lie very far apart at their exit—further apart than in some of the large Ostriches. The rostrum of the basisphenoid (*r.b.s.*) is keeled in both species—most so in *T. robustus*, in which it extends further forwards than in *T. variegatus*. The anterior pterygoid processes (*a.p.*) are wider in the former than in the latter, but there is no evident difference in the posterior outgrowths; in both the spurs that often grow from the basitemporals are entirely aborted. The extreme shallowness of the ear-drum, arising from the shortness of the exoccipital wings (Plate XV. fig. 1, *e.o.*), is well shown in both; the occipital plane agrees, on the whole, with that of the Apteryx, but the edge of the parietals overhangs the superoccipital instead of graduating insensibly into it (Plate XV. fig. 1). There is more bone in the septum of *T. variegatus* than in that of *T. robustus*, but in the latter the presphenoid reaches the conjunction of the basisphenoid with the perpendicular ethmoid; it does not in *T. variegatus* (Plate XV. figs. 1 & 4, *p.s.*). In the latter the anterior sphenoid stands in front of the orbital plates of the frontal; in *T. robustus* it passes behind those plates. In both there is a most unique display of sutures at this part, these being most clearly seen in *T. variegatus* (Plate XV. figs. 1 & 3), although the bird (as Mr. BARTLETT informs me) was in its fourth year. In this bird the alisphenoid (*a.s.*) is distinct from the frontal (*f.*) above, from the basisphenoid (*b.s.*) below, and from the orbito-sphenoid (*o.s.*) in front; also from the postfrontal epiphysis at its supero-external angle (*p.f.*). The extremely small presphenoid and orbito-sphenoids are still separated from their surroundings by distinct sutures, the upper bar of the ethmoid (fig. 1, *p.e.*) nearly reaching the alisphenoids, and nearly insulating the interorbital fenestra behind—a most unusual abortion of the anterior sphenoid, as compared with the Mammal, the Reptile, or even with some of the Struthionidæ, but perfectly ornithic. The sagittal and lambdoidal sutures (Plate XV. fig. 3) are thoroughly obliterated; but the coronal suture (Plate XV. fig. 3) is as completely open as in the Lizard, and joins that between the alisphenoid and frontal on each side. In *T. robustus* the alisphenoid has joined itself to the basisphenoid below; the other sutures are the same, and the important coronal suture was not drawn in my other paper because the skull was diseased at top; afterwards I found the suture thoroughly open at the sides, as in *T. variegatus*. This is only part of what is reptilian in these birds; and it is curiously in contrast with the very solidified condition of the rest of the skull. In *T. variegatus* the suture between the high prepituitary portion of the basisphenoid and the lower bar of the ethmoid is quite visible; and in both the junction of the rostrum with the ethmo-presphenoidal plate can be seen, although anchylosis has taken place in some degree. In both the perpendicular ethmoid is continued on into the septum nasi, the whole being one bone, reaching from the exit of the optic nerves to no great distance from the solid part of the intermaxillary. No distinction between the upper and vertical ethmoid can be seen, and in *T. robustus* the aliethmoid, pars plana, and basal part of the inferior turbinal have coalesced with each other, and with the antorbital plate of the lacrymal, thus agreeing with the Apteryx. In *T. variegatus*, however, the boundaries of all these parts can be clearly seen as fine sutures (Plate XV. fig. 13), the upper and perpendicular part (*eth.*, *p.e.*) only having lost their distinctness. In one important point the stouter kind (*T. robustus*) differs from the other, and approaches the typical birds, viz., in the commencement of the great ethmo-septal cleft (Plate XV. fig. 8, *c.f.c.*), by which the upper jaw is allowed to be hinged in to the head. All birds go through the struthious stage in their embryonic condition, and at a further stage agree with this Tinamou. In *T. variegatus*, so nearly allied, this cleft does not appear; this shows the importance of not drawing our conclusions too hastily, and of the necessity for suspecting mere negative evidence—the "instance contradictory" may turn up in the hundredth species*. There is a very regular posterior nasal zone, in which ossification takes place freely (Plate XV. fig. 13, *eth.*, *a.i.t.*); on a sudden it stops, and then all the rest, save the axis and a little of the roof, or roots of the inferior turbinals, is cartilaginous; yet in *T. robustus* some dendritic bony threads creep forwards into these cartilages; there are no true upper and middle turbinal outgrowths; and the ossified part of the inferior turbinal is closely conjoined to the front of the outstanding part of the "pars plana" (Plate XV. fig. 13, *p.p.*, *al.s.*); its upper part is vertical, and nearly parallel with the perpendicular ethmoid (*p.e.*), thus moving upwards to join the slanting overhanging aliethmoidal lamella (Plate XV. fig. 13, *al.e.*), the only rudiment of the upper turbinal mass and cribriform plate of the mammal. Anteriorly, this lamella, where it grows out of the septum nasi, becomes the outer nasal wall and root of the inferior turbinal (Plate XV. figs. 9, 13, *al.s.*); it passes nearly halfway down in a convex manner, and then becomes double, the outer plate forming a new convexity, and the inner turning upwards and inwards to coil rather more than twice (Plate XV. fig. 9, *it.b.*). Further forwards its coil is only one and a third (fig. 10), and then in the alinasal region, when the alæ are free of the septum, it simply passes inwards and a little downwards, but like the alinasal of the Rhea, its outgrowth is a little more labyrinthic than the inferior turbinal, for it gives off the rudiments of three other plates (Plate XV. fig. 11). The complication of these turbinal growths in the alinasal region is an interesting character. I must refer to my other paper for a description of the facial structures of the Tinamou, merely remarking that the anterior part of the palatine (Plate XV. fig. 2, *pa.*) is much shorter in *T. variegatus*, and that the metapterygoid process of the os quadratum (*q.*) is much broader (*ralline*) than in

---

* Now the hand of DARWIN is not with me in all this; nor need the patient positive observer be anxious as to what these things will grow; the truth of the matter being ascertained, let come of it what will, we are not careful to answer in this matter.

---

* As far as I have seen there is no "mesopterygoid" in the typical "Struthionidæ," nor in *Tinamus variegatus* and *robustus*; an "instance contradictory" turns up, however, in *T. brasiliensis* sive *major*, where it is very large, and permanently distinct.

T. robustus. The nasal processes of the intermaxillaries (*px.*) are entirely soldered together in both kinds, but they are very pluvialine, as may be seen by comparing them with those of the Lapwing; they also agree, in the main, with those of the Apteryx, save that the tips come close together and are very narrow, as in most of the "Pluvialinæ" (Plate XV. fig. 3, *px.*). The lateral grooves, the beautiful vascular punctæ, the short angular processes, and the large, long, flat palatine processes of the intermaxillaries (Plate XV. fig. 3) are all strictly struthious, as may be seen by a comparison of the numerous figures showing these parts. In *T. variegatus* the ascending process of the prevomer is small, and the pedate proximal process is not marked out from the body of the bone (Plate XV. fig. 2, *p.v.*); in *T. robustus*, however, we come nearer the "Gallinaceæ" proper, the Megapods, the Sandgrouse, the Hemipods, and the innumerable Corvine, Sylviine, Fringilline, and other related groups in the differentiation of this remarkable process, long supposed to be the inferior turbinal. In *T. robustus*, this narrow, flat, curled, gradually widening process is turned somewhat backward; and as it passes also inwards comes down upon the anterior process of the palatine, and coalesces with its upper and inner edge (Plate XV. figs. 6, 7, *p.v.*). The delicate angular process of the intermaxillary is 1½ line long in *T. variegatus*, and 6 lines long in *T. robustus*, in which it is continued to the foot of the descending process of the nasal (Plate XV. figs. 6, 7); feeble, indeed, and clubbed at its end. The very large "vomer" (Plate XV. fig. 2, *v.*), deeply cleft behind, and having two long forks in front, is struthious enough; in the Hemipods it is extremely short and broad; in the Sandgrouse and Pigeons seldom present at all; in the "Phasianinæ" and "Tetraoninæ" it is very feeble, and not much stronger in the Megapods; in the Plovers and Rails it attains a medium size; but the Tinamous hold with the large Ostriches in this most important and very reliable character. The nasals (*n.*) of the Tinamous come still nearer to those of the Plovers than do those of the Apteryx; but the posterior portion is so completely amalgamated with the frontal, ethmoid, and lacrymal, that it cannot be told how much nearer they came to the Plover's nasals. To all appearance there is but little difference; and so also as to the frontals (*f.*), especially if we compare the Tinamous skull with such species as have but little of the frontal developed below and beyond the nasal gland. So also the lacrymals (*l.*); these have lost their superorbital process, and like the Cassowary, have no antorbital fenestra. The narrowest part of the combined frontals is only 3 lines in *T. robustus*, scarcely more than 2 lines in *T. variegatus*; the outer margin being also bevelled deeply for the nasal gland, and that also almost to the postorbital region. But in *Vanellus*, *Charadrius*, and others, the frontals run below and beyond the gland, and are very wide; I have already shown (Trans. Zool. Soc. vol. v.) how this is supplemented in *Tinamus robustus*. In that bird the superorbital chain of bones is single, with one intercalary bone on each side; but *T. variegatus* has two rows (Plate XV. fig. 3, *s.o.b.*) all along, about 14 or 15 on each side. I have already compared these to the superorbitals of the Skink-lizards, Blind-worms, and Trigonal Cayman, and have noticed their presence in another bird, viz., the Trumpeter (*Psophia crepitans*), only in an enfeebled form. I would now add to this category the marginal plates of the cranial bucklers of the recent and extinct ganoid Fish, viz., *Sturio*, *Dipterus*, *Osteolepis.* The bone in the Sturgeon, which Professor HUXLEY has compared to the so-called squamosal (pterotic) of the osseous fish, is merely one of this category; so also are those in front of it, one of these being the homologue of the postorbital bone of the Reptilia, and a mere splint-bone, and not the homologue of the postfrontal of the Fish and the Bird. I am aware that in the Skinks and Blind-worms the process of ossification has affected much more of the derm-fibres than in the bird, only a thin layer being left as a *quick* for the epidermic cells, which form the investing scales; this, however, does not alter the homology of the parts; nor would it if the whole skin were converted into hard, naked, enamelled bone. Any one familiar with the histological development of these parts will make no difficulty here.

The mandibles of the Tinamou (Zool. Trans. vol. v. pl. 40, figs. 3, 6, 7) are as truly struthious; the thoroughly cemented symphysis is 5½ lines in extent in *T. variegatus*, and the lateral lines and the large punctæ are the precise counterpart of those in the upper jaw. The distinctness of the mandibular splints is feebly shown, and there is no open space; the angles of the jaws (external and internal) are but little produced; the latter, the most important, being the homologue of the "manubrium mallei," is in a low developmental condition, this part being relatively largest in the little "hammer" of the Mammal, and completely wanting in the large "articulare" of the osseous Fish. They are both large in the Gallo-anserine series of birds; and the internal angular process is large in Finches and Crows.

The os hyoides (Plate XV. fig. 12) is much like that of the Gallinaceæ in outward form, but is in reality much less developed; the narrow cerato-hyal cartilages (*c.h.*) have almost coalesced; they are distinct at the middle, and they diverge behind. The basi-hyal (*b.h.*) is not distinct from the uro-hyal (*u.h.*); but a short bone is developed in the proximal part of the latter; it is rounded, and blunt at the end. The lowest thyro-hyal (*th.* 1) is almost entirely ossified, and the upper (*th.* 2) has only the tip cartilaginous; these parts come very near to those of the Fowls, but they have a bony basi-hyal also; and in them the posterior two-thirds of the partly coalesced cerato-hyals has become bony.

Description of the Plates*.

PLATE VII.

Struthio camelus, "A." One-third of incubating period.

Fig. 1. Primordial skull, seen from above; 3 diameters: *b.o.* basioccipital; *n.c.* notochord; *e.o.* exoccipital; *f.m.* foramen magnum; *s.o.* superoccipital; 9. 9th nerve; *a.s.c.* anterior semicircular canal; 5. trigeminal nerve; *a.s.* alisphenoid; *i.c.* internal carotid; *pt.s.* pituitary space; *p.cl.* posterior clinoid; *a.cl.* anterior clinoid; 2. optic nerve; *o.s.* orbito-sphenoid; *cr.g.* crista galli; *eth.* ethmoid; *p.p.* pars plana; *al.e.* aliethmoid; *al.s.* aliseptal; *al.n.* alinasal; *p.n.* prenasal.

Fig. 2. Vertical section of the same skull; 3 diameters: *o.c.* occipital condyle; 8. 8th nerve; 7. 7th nerve; *b.s.* basisphenoid; *s.c.* sinus canal; *a.p.* anterior pterygoid process; *p.s.* presphenoid; *r.b.s.* rostrum of basisphenoid; *p.e.* perpendicular ethmoid; *s.n.* septum nasi; 1. olfactory nerve.

Fig. 3. Side view of entire skull; 3 diameters: *m.t.* membrana tympani; *n.g.* nasal gland; *d.* dentary; *s.a.* surangular; *a.* angular; *ar.* articular.

Fig. 4. Lower view of ditto; 3 diameters: *b.t.* basitemporal; *p.g.* pterygoid; *pa.* palatine; *p.v.* prevomer; *v.* vomer.

Fig. 5. Upper view of the same skull; 3 diameters: *q.* quadrato-jugal; *j.* jugal; *n.* nasal; *l.* lacrymal; *p.x.* premaxillary.

Fig. 6. End view of the entire of skull of the same; 3 diameters: *fo.* fontanelle; *f.* frontal; *p.* parietal; *sq.* squamosal; *q.* os quadratum; *p.s.c.* posterior semicircular canal; *h.s.c.* horizontal semicircular canal.

Fig. 7. Os hyoides of the same; 3 diameters: *c.h.* cerato-hyals; *b.h.* basi-hyal; *u.h.* urohyal; *th.* 1. lower thyro-hyal; *th.* 2. upper ditto.

PLATE VIII.

Fig. 1. Side view of skull of *Struthio camelus*, "B.;" 2 diameters.

Fig. 2. Lower view of the same; 2 diameters: *st.* stapes; *p.r.p.* posterior pterygoid process.

Fig. 3. Upper view of skull of *Struthio*, "B.;" 2 diameters.

Fig. 4. End view of skull of *Struthio camelus*, "B.;" 2 diameters: *p.c.f.* posterior condyloid foramen; *op.* opisthotic.

Fig. 5. End of mandible, seen from above, of *Struthio*, "C.:" *pn.* pneumatic foramen.

---

* The *cartilage-bones* are distinguished from the *splint-bones* in the Plates by being sparsely dotted; the cartilage itself is finely and closely dotted, and the membranous spaces are cross-barred.

Fig. 6. Os hyoides of *Struthio*, "C.;" 2 diameters.

Fig. 7. Vertical section of anterior part of skull of *Struthio*, "C.;" 2 diameters. The oblique lines 1–1 to 6–6 show where the sections in Plate X. were taken, viz. 1, 1 to fig. 1, 2, 2 to fig. 2, &c. on to 6, 6, which answers to fig. 6.

Fig. 8. End view of skull of *Struthio*, "C.;" 2 diameters.

Fig. 9. Part of primordial skull of *Struthio*, "C.;" 2 diameters: *eu.* Eustachian groove; *a.r.q.* articular facet on the exoccipital wing for os quadratum; *f.s.r.* fenestra rotunda vel cochleæ.

Fig. 10. Vertical section of the skull of *Struthio*, "C.;" 2 diameters: 5. foramen ovale, with f. rotundum in front of it; *m.k.* MECKEL'S cartilage; *sp.* splenial; *cr.* coronoid.

Fig. 11. Section taken transversely through pars plana, and end of inferior turbinal of *Struthio*, "C.;" 4 diameters: *m.t.b.* middle turbinal fold; *i.t.b.* base of inferior turbinal; *ext.* external aspect of pars plana; *int.* internal ditto.

PLATE IX.

Fig. 1. *Rhea americana*, var. Primordial skull, seen from above: *p.f.* postfrontal; 2 diameters.

Fig. 2. Side view; 2 diameters.

Fig. 3. Entire skull, side view: *d.n.g.* duct of nasal gland; 2 diameters.

Fig. 4. Entire skull, lower view; 2 diameters.

Fig. 5. Entire skull, upper view; 2 diameters.

Fig. 6. Entire skull, end view; 2 diameters.

Fig. 7. Os hyoides; 2 diameters.

PLATE X.

Fig. 1. Transversely vertical section of skull of *Struthio*, "C." in front of the eye-ball, seen from behind; 4 diameters: *a.i.t.* angle of inferior turbinal.

Fig. 2. A similar section further forwards; 4 diameters: *n.px.* nasal process of premaxillary; *i.t.* inferior turbinal; *s.n.* septum nasi.

Fig. 3. Another section a line or two in advance of the last; 4 diameters: *n.t.* nasal turbinal.

Fig. 4. Another section in front of the last; 4 diameters: *a.px.* angle of premaxillary.

Fig. 5. Another through the alæ nasi; 4 diameters.

Fig. 6. Another in front of the alæ nasi; 4 diameters.

Fig. 7. Vertical longitudinal section of primordial skull of *Rhea*; 2 diameters: *i.o.s.* interorbital space; 5 *a.* foramen rotundum.

Fig. 8. *Rhea Americana*, var. Part of skull, side view; 4 diameters. The outer part is pared away to show the semicircular canals.

Fig. 9. Section of upper ethmoid, showing its alæ, in the Rhea.

Fig. 10. Horizontal section through pars plana of *Rhea*; 4 diameters.

Fig. 11. Front view of pars plana and middle turbinal of *Rhea*, showing a section of the lower turbinal; 4 diameters.

Fig. 12. Part of fig. 13; 8 diameters.

Fig. 13. Section of combined upper and perpendicular ethmoids of *Rhea*, showing their junction and the coalescence of the right and left lamellæ of the perpendicular part; 4 diameters.

Fig. 14. Ditto, section through the widest part of the inferior turbinals of *Rhea*; 4 diameters.

Fig. 15. Transversely vertical section through the septum nasi and lower turbinal of *Rhea* further forwards; 4 diameters.

Fig. 16. Similar section through the alæ nasi of the same, showing the fibrous pads attached to the nasal turbinals; 4 diameters.

Fig. 17. View from within of pars plana of the Mooruk, with its middle turbinal, simple upper turbinal semi-scroll, and posterior part of inferior turbinal; 4 diameters.

Fig. 18. Ditto, section through anterior part of ethmoid of the same, and posterior part of inferior turbinal; 4 diameters.

Fig. 19. Ditto, section through widest part of nasals, and fullest part of inferior turbinals; 4 diameters.

Fig. 20. Ditto, section through the hinder part of ethmoid of the Mooruk, and through frontals and anterior sphenoid; 4 diameters.

PLATE XI.

Fig. 1. *Dromæus irroratus*, "A." Side view of skull; 2 diameters: *i.e.s.* intereth-moidal space.

Fig. 2. Ditto, basal view; 2 diameters.

Fig. 3. Ditto, upper view; 2 diameters.

Fig. 4. Ditto, ditto, end view; 2 diameters.

Fig. 5. Upper view of part of lower jaw of the same Emu; 4 diameters: *sp.* splenial.

Fig. 6. Ditto, ditto, proximal end seen from above; 4 diameters: *c.r.* coronoid.

Fig. 7. Ditto, obliquely basal view of hinder part of skull; 4 diameters: *m.p.g.* metapterygoid; *eu.* Eustachian groove; *sy.* symplectic, with its anterior and posterior rays given off near the shaft of the "stapes."

Fig. 8. Ditto, os hyoides; 2 diameters.

Fig. 9. End view of skull of "*Dromæus* B.;" 1½ diameter.

Fig. 10. *Dromæus Novæ-Hollandiæ* ("B."). Part of skull and face, side view; 3 diameters: *ep.* epiotic; *m.p.q.* metapterygoid process of os quadratum.

PLATE XII.

Fig. 1. Side view of skull of "*Dromæus*, B."; 1½ diameter.
Fig. 2. Basal view of skull; 1½ diameter.
Fig. 3. Upper view of ditto; 1½ diameter.
Fig. 4. Side view of part of the same skull; 3 diameters.
Fig. 5. Part of the same preparation, shown in Plate XI. fig. 10; 6 diameters: *sy.* symplectic; *an.* anterior process; *p.r.* posterior process.
Fig. 6. End view of primordial skull of *Dromæus irroratus* ("C."), two months old; 2 diameters.
Fig. 7. Upper, middle, and hinder part of inferior turbinal, seen from within, of *Dromæus*, "D." (2 diameters).
Fig. 8. Ditto, the same preparation seen from the front.
Fig. 9. *Dromæus irroratus* ("D."), half-grown. Section through fullest part of inferior turbinal; 2 diameters.

PLATE XIII.

Fig. 1. Basal view of skull of "*Dromæus*, C.;" 1½ diameter.
Fig. 2. Side view (external) of the same; 1½ diameter.
Fig. 3. The same, seen from above; 1½ diameter.
Fig. 4. Internal view of hinder part of ditto; 1½ diameter.
Fig. 5. Side view of ethmoid, showing part of interorbital, and part of internasal septum; 1½ diameter.
Fig. 6. Hinder view of same; 1½ diameter.
Fig. 7. The skull, front view, as seen from the back of the orbits; 1½ diameter.
Fig. 8. Front view of lacrymal; 1½ diameter.
Fig. 9. Proximal upper view of mandible; 1½ diameter.
Fig. 10. Proximal end view of mandible; 1½ diameter.
Fig. 11. Proximal part of mandible, seen from below; 1½ diameter.
Fig. 12. Facial bones of *Dromæus irroratus* ("A."), seen from above: *m.x.* maxillary; 4 diameters.
Fig. 13. Side view of the same, showing both the maxillary and the oblique (proximal) process of the prevomer.

PLATE XIV.

Casuarinus Bennettii (full period).

Fig. 1. Side view of skull; 2 diameters.
Fig. 2. Lower view of skull; 2 diameters.
Fig. 3. Upper view of skull; 2 diameters.

Fig. 4. End view of skull; 2 diameters.

Fig. 5. Side view of skull from within; 2 diameters.

Fig. 6. Side view of skull of do. with the outer part pared away to show the structures of the internal sac; 4 diameters: *c.h.l.* cochlea; *c.f.* cerebellar fossa.

Fig. 7. Transversely vertical section of skull of *C. Bennettii*, seen close behind the lateral ethmoids; 2 diameters.

Fig. 8. A similar section through the interorbital space; 4 diameters.

Fig. 9. Horizontal section through the left pars plana with its middle turbinal tent; 8 diameters.

Fig. 10. Another section at the lower part of the turbinal, showing a bifurcation of the turbinal outgrowth; 8 diameters.

Fig. 11. A similar section a line lower down than fig. 9, showing the anterior opening into the tent; 8 diameters.

Fig. 12. Os hyoides of *C. Bennettii*; 2 diameters.

PLATE XV.

Fig. 1. Side view of skull of *Tinamus variegatus*, adult (4th year): *s.o.b.* superorbitals; 2 diameters.

Fig. 2. Basal view of skull; 2 diameters.

Fig. 3. Upper view of skull; 2 diameters.

Fig. 4. Part of fig. 2; 4 diameters; showing the anterior sphenoid and its surroundings: *f.* orbital plate of frontal.

Fig. 5. *Tinamus robustus*, adult. Inside of anterior part of skull; 4 diameters.

Fig. 6. *Tinamus robustus*, part of the face seen from above; 4 diameters: *p.p.v.* proximal process of prevomer.

Fig. 7. *Tinamus robustus*, side view: *p.x.* angle of premaxillary.

Fig. 8. *Tinamus robustus*, part of ethmoid and nasal septum, side view; 4 diameters: *c.f.c.* rudiment of cranio-facial cleft.

Fig. 9. Section through fullest part of the inferior turbinals of *Tinamus variegatus*; 6 diameters.

Fig. 10. Another section further forwards; 6 diameters.

Fig. 11. Another through the alæ nasi, and in front of the septum nasi; 6 diameters.

Fig. 12. Os hyoides of *Tinamus variegatus*; 2 diameters.

Fig. 13. *Tinamus variegatus*, adult. Side view of nasal structures, with the lateral bones removed; 4 diameters.

Fig. 14. Inferior turbinals of *Psophia crepitans* without the prepalatine splints; 4 diameters.

IX. *Account of Experiments on the Flexural and Torsional Rigidity of a Glass Rod, leading to the Determination of the Rigidity of Glass.* *By* JOSEPH D. EVERETT, *D.C.L., Assistant to the Professor of Mathematics in the University of Glasgow. Communicated by Professor* W. THOMSON, *F.R.S.*

Received February 1,—Read February 22, 1866.

THESE experiments were conducted in the Physical Laboratory of Glasgow University during the summer vacation of 1865, upon a plan devised by Professor W. THOMSON, which may be briefly described as follows:—

A cylindrical rod of glass is subjected to a bending couple of known moment, applied near its ends. The amount of bending produced in the central portion of the rod is measured by means of two mirrors, rigidly attached to the rod at distances of several diameters from each end, which form by reflexion upon a screen two images of a fine wire placed in front of a lamp-flame. The separation or approach of these two images, which takes place on applying the bending couple, serves to determine the amount of flexure.

In like manner, when a twisting couple is applied, the separation or approach of the images serves to determine the amount of torsion.

The following are the details of the arrangement.

A B (Plate XVI. fig. 2) is the glass rod, firmly held at both ends in the brass sockets A, B which form the extremities of the hollow brass arms A C, B D. Each of these arms is furnished with two pairs of sharply pointed cones, exactly opposite to each other, at E, C, F, D, of which those at E, F serve as feet for supporting the apparatus, while those at C and D support the weights used for producing flexure and torsion. The two distances E C, F D are exactly equal. There are joints in the arms at E, F, the axes of the joints being the same as those of the cones; and for torsion experiments these are turned to a right angle on opposite sides, as shown in bird's eye view at fig. 3, where the same letters denote the same parts as in fig. 2. In flexure experiments the arms are in the same straight line with the glass rod, as shown in fig. 2. In both arrangements it is obvious that when equal weights are hung at C and D, their effect upon the rod is equivalent to a couple whose moment is the force of gravity on one of the weights multiplied by one of the equal distances E C, F D. In fig. 2 this couple bends the rod without twisting it, and in fig. 3 twists without bending it.

In the final series of experiments the apparatus was made to rest on three feet instead of two; one of the points, as F, being replaced by two points about an inch apart, lying in a line at right angles to that joining E F.

G K, H L are light arms of brass clamped to the glass rod by screws G, H, at the distance of several diameters of the rod from the sockets A, B, and carrying at their other extremities the semicircular mirrors **M, N**, which are represented on a larger scale in figs. 4, 5. Each mirror is attached to its supporting arm by a vertical rod *a b*, turning in a socket at *a*, and having a joint at *b*, by means of which the plane of the mirror can be turned to or from the vertical. By these two motions we can cause the image formed upon the screen to move either horizontally or vertically. The mirrors always face the screen. In flexure experiments their planes are perpendicular, and in torsion experiments parallel to the length of the glass rod, as shown in figs. 4, 5 respectively. P P, Q Q are rectangular frames of iron for supporting the apparatus.

Fig. 1 exhibits the general arrangement for flexure experiments. A is the apparatus above described, D a paraffin lamp, C a frame for supporting a fine brass wire stretched horizontally on a level with the middle of the flame, and nearly in contact with the glass shade of the lamp. As seen from the mirrors, this wire appears as a fine dark horizontal line passing through the flame. B is an achromatic lens of 4 feet focal length, mounted on what is equivalent to a universal joint. The rays of light from the flame and wire pass through this lens to the mirrors, and after reflexion pass outside the lens to the screen E, on which two images of the wire (one from each mirror) are formed, appearing as horizontal lines of darkness in the midst of large spots of light. The clearest portions of the two images were brought, by adjustment of the mirrors, into the same vertical line, and the distance of their centres was directly measured with a rule divided at the edge to millimetres. The images were sufficiently narrow to be easily bisected by eye, and the readings were taken to tenths of a millimetre.

In torsion experiments, the apparatus A was placed so that the glass rod was parallel instead of perpendicular to the screen, but the mirrors were turned so as still to face the screen, and the appearance of the images was the same as above described. In both cases the images could be made either to approach or recede from one another on hanging on the weights, by adjusting the mirrors so as to cause one or the other of the images to be in the first instance uppermost. In some of the experiments they approached, in others they receded. In all the experiments they were nearly on a level with the mirrors, and the rays, both direct and reflected, were nearly perpendicular to the screen.

The mirror-arms G K, H L, fig. 2, were so adjusted that one of the mirrors was a little behind, and at the same time a little to one side of the other, as represented in figs. 4, 5; the former being a side and the latter a front view. They were just far enough apart in both directions to prevent any risk of their coming in contact when flexure and torsion were produced in the glass rod.

As the portion of the rod whose flexure and torsion are measured is that which lies between the clamps G, H, it was necessary to ensure that these should always be in the same places; and to this end two measuring sticks, cut to convenient lengths, were employed, and whenever it was necessary to unscrew and readjust the clamps, the distances between B and H and between H and G were made to fit these sticks.

After a great number of preliminary experiments, in which improvements were gradually introduced in the apparatus and mode of observation, the final observations were made in the manner above described. They consisted of a set of flexure observations with the rod turned into ten different positions, differing from one another by tenths of a revolution, and of a set of torsion observations with the arms alternately fixed. The fixing of one arm was necessary to the attainment of steadiness in torsion observations, as without it the apparatus would have oscillated with a see-saw motion, and was effected by inserting a flat piece of wood, W (fig. 3), underneath, and laying a weight (not shown in fig. 3) on the top of the arm. The arrangement will be better understood from an inspection of fig. 6, where X represents the weight laid on the arm. As the experiments with right arm fixed and left arm fixed were equally numerous, the mean result is free from errors arising from want of perfect symmetry in the two arms.

The weights employed were the same for torsion as for flexure. They were lead weights of 50 and 100 grammes, and were accurately tested. Every set of observations was symmetrical with respect to the zero or unstrained condition of the rod, consisting either of five observations in the order 0, 50 grms., 100 grms., 50 grms., 0, or of five observations in the order 100 grms., 50 grms., 0, 50 grms., 100 grms.

The following were the numerical determinations obtained:—

Torsion.

	centimetres.
Mean separation of images per gramme	·053185
Mean distance of mirrors from screen	277·3

Flexure.

Mean separation of images per gramme in ten equidifferent positions, ·04175, ·04185, ·04069, ·04160, ·04112, ·04243, ·04062, ·04100, ·04132, ·04203, giving a gross mean of	·04144
Mean distance of mirrors from screen	271·8

For both Torsion and Flexure.

Length of glass rod between clamps	28·0
Arm of couple	31·4

As a specimen of the amount of consistency between different readings, as well as of the method employed in their reduction, I will here transcribe the last set of flexure observations—last in order of time, but sixth in order of position. The first column contains the weight (in grammes) acting at each arm; the second, the distance of the images; the third, the amount of separation or approach of the images as compared with the zero or unweighted distance. The mean separation or approach per gramme is computed by dividing the sum of the numbers in the third column by the sum of those in the first.

100	9·29	4·29
50	7·16	2·16
0	5·00	
50	7·12	2·12
100	9·24	4·24
		300) 12·81
		·0427 effect per gramme.

0	5·00	
50	7·11	2·11
100	9·23	4·235
50	7·10	2·11
0	4·99	
		200) 8·455
		·0423 effect per gramme

100	9·22	4·24
50	7·09	2·11
0	4·98	
50	7·08	2·10
100	9·22	4·24
		300) 12·69
		·0423 effect per gramme.

The mean of ·0427, ·0423, ·0423 is ·04243, which is adopted as the mean effect per gramme in this position of the rod.

I may here state that, from a careful analysis of several observations, both of torsion and flexure, I have come to the conclusion that the mean separation of images produced by weights of 100 grammes is, within the limits of accuracy attainable in these experiments, precisely double of that produced by weights of 50 grammes. In several sets of observations the deviation from strict proportionality amounted only to about 1 part in 500, and this deviation was sometimes on one side and sometimes on the other.

When the experiments above described were concluded, the ends of the glass rod were cut off just outside the clamps, and the remaining portion was weighed in air and water. The weights were respectively 40·317 and 26·620 grammes, showing a loss in water of 13·697 grammes; and since a gramme is the weight of a cubic centimetre of water, this last number expresses the volume of the rod in centimetres. The length was found to be 28·2; hence the mean sectional area is ·48571, and the mean radius ·39321. No correction is applied for the temperature of the water (9° Cent.), as its amount would be only about 1 part in 5000.

From the data above given the following elements will now be computed:—

f, the flexural rigidity of the rod, or the reciprocal of the amount of curvature per unit length of rod, per unit moment of bending couple.

t, the torsional rigidity of the rod, or the reciprocal of the amount of twist per unit length of rod, per unit moment of twisting couple.

These two elements are functions of the thickness of the rod as well as of the material of which it is composed. The following are functions of the material only:—

n, the absolute rigidity, or reciprocal of the amount of shear per unit shearing force.

M, YOUNG'S modulus of elasticity, or reciprocal of the fraction of its length, by which a prismatic or cylindric rod of unit section is lengthened per unit stretching force.

k, the resistance to compression, in such sense that $\frac{1}{k}$ is the compressibility, or the fraction of itself by which the volume is diminished under unit pressure per unit area over the whole surface.

σ, POISSON'S ratio, or the ratio of transverse contraction (in one dimension) to longitudinal extension when a prismatic or cylindric rod is stretched longitudinally. This ratio was supposed by POISSON to have the same value ($\frac{1}{4}$) for all materials, and was first shown by STOKES* to be a function of two independent elements whose mutual relation is different for different substances, and must be determined for each by experiment.

Of these quantities, σ is the only one whose numerical value is independent of the units employed. Our units are the centimetre and the weight of a gramme at Glasgow, where the acceleration due to gravity is 981·4 centimetres per second generated per second.

To find f and t. Since the deviation of a reflected ray is double the angle through which the mirror is turned, the relative angular movements of the mirrors per gramme, in flexure and torsion respectively, are

$$\frac{\cdot 04144}{2\times 271\cdot 8} \text{ and } \frac{\cdot 053185}{2\times 277\cdot 3};$$

hence, since length of rod is 28·0 and arm of couple 31·4,

$$f=31\cdot 4\times 28\cdot 0\times \frac{543\cdot 6}{\cdot 04144}=11{,}533{,}000,$$

$$t=31\cdot 4\times 28\cdot 0\times \frac{554\cdot 6}{\cdot 053185}= 9{,}168{,}200.$$

The logarithms of f and t are 7·06195 and 6·96228.

---

* Cambridge Philosophical Transactions, April 1845.

For finding M, n, k, and σ the formulæ are

$$M=\frac{4f}{\pi r^4}{}^{\ast},\quad n=\frac{2t}{\pi r^4}{}^{\dagger},\quad \frac{1}{3k}=\frac{3}{M}-\frac{1}{n}{}^{\ddagger},\quad \sigma=\frac{1}{2}\frac{M}{n}-1=\frac{f}{t}-1\,\S,$$

r denoting the radius of the rod $=\cdot39321$. Hence we find

$$\begin{aligned} M&=614{,}330{,}000,\\ n&=244{,}170{,}000,\\ k&=423{,}010{,}000; \end{aligned}$$

and since $\log f-\log t=7\cdot06195-6\cdot96228=\cdot09967=\log 1\cdot258$, we have

$$\sigma=\cdot258.$$

As regards the accuracy of these results, I think a fair estimate of the probable error of M and n is about $\frac{1}{2}$ per cent. for each; hence it is found by the proper investigation that the probable errors of k and σ are each about 4 per cent.

The rod was of flint glass, and was from the works of JAMES COUPER and SONS, Glasgow.

It is intended shortly to continue our experiments, with some modifications in the apparatus, and to determine the values of the constants M, n, k, and σ for a variety of substances.

Experiments for determining the value of σ for steel and brass have been described by KIRCHHOFF[||].

The method of observation described in the present paper possesses the following advantages over that of KIRCHHOFF:—

1. The portion of the glass rod whose flexure and torsion are observed is sufficiently distant from the places where external forces are applied to be free from the irregularities which exist in their neighbourhood.

In KIRCHHOFF'S experiments the rod was subjected to external forces applied at three places in its length (being held in the middle and weighed at the ends), and the flexure and torsion observed were those of the whole rod.

2. Both the bending and twisting couple are uniform through the whole length.

In KIRCHHOFF'S experiments the bending couple is greatest at the middle of the rod and diminishes to zero at the ends, whereas the twisting couple is uniform through the whole length. If, then, the middle of the rod be more or less stiff than the ends, the comparison between flexure and torsion is fallacious.

---

[*] The flexural rigidity of a cylindrical rod is equal to YOUNG'S Modulus multiplied by the moment of inertia of a circular section about a diameter.—§ 715, THOMSON and TAIT'S 'Natural Philosophy.'

[†] The torsional rigidity of a cylindrical rod is equal to the absolute rigidity multiplied by the moment of inertia of a circular section about the centre.—§ 701, *ibid.*

[‡] Easily derived from § 684, *ibid.*

[§] § 694, *ibid.*

[||] POGGENDORFF'S 'Annalen' for 1859, vol. cviii. page 369; see also Philosophical Magazine, January 1862, page 28.

3. Kirchhoff determined the value of only one constant σ, whereas we determine by experiment two independent constants M and n, from which two others, σ and k, are computed.

On the other hand, our method has the disadvantage of involving the unclamping and reclamping of the mirrors between experiments on torsion and those of flexure, an operation which introduces risk of bringing slightly different portions of the rod under observation in the two cases. In future experiments it is intended to remove this defect.

No notice has been taken of possible effects due to the flexure of the arms which support the mirrors. It is assumed that these effects are the same when the rod is bent or twisted as when it is free, and on this assumption they will not affect the results.

Again, the arms of the applied couples are not strictly equal to the distances E C, F D (figs. 2, 3), unless the brass arms E C, F D are horizontal, and the further they depart from horizontality the shorter do the arms of the couples become. In some of the preliminary experiments, this deviation was measured, and when appreciable, allowed for. In the final experiments it was so small and so nearly the same in torsion and flexure that it is assumed to produce no appreciable error.

Similar remarks apply to deviation from horizontality in the rays of light reflected from the mirrors to the screen.

The following values of σ for different substances have been found by other experimenters:—

Kirchhoff, by the method above alluded to, found for steel ·294, brass ·387.

Wertheim, by a different method, glass (crystal) about ·33.

Professor J. Clerk Maxwell, by experiments in 1850, glass ·332, iron ·267.

It will be observed that our own value for flint glass, ·258, is smaller than any of these.

X. *On the Laws of Connexion between the Conditions of a Chemical Change and its Amount.*

By A. Vernon Harcourt, *M.A., Student of Christ Church, and Demonstrator of Chemistry in the University of Oxford; and* William Esson, *M.A., Fellow of Merton College, Oxford**. *Communicated by Sir* B. C. Brodie, *Bart., F.R.S., Professor of Chemistry in the University of Oxford.*

Received September 5,—Read November 16, 1865.

I. *On the Reaction of Permanganic and Oxalic Acids.*

When any substances are brought together under circumstances under which they act chemically one upon another, a change takes place which consists in the disappearance of a part of the original substances and the appearance of an equal weight of other substances in their place. This change continues, if the circumstances remain the same, until the whole of one of the substances taking part in it has disappeared. Its total amount is therefore ultimately determined by the amount of that substance which was originally present in the smallest proportional quantity. The attainment of this limit, as will be shown, requires theoretically an infinite time, but the velocity of chemical change is so great that the practical limit of an inappreciable residue is in most cases speedily reached. Owing perhaps to this fact, chemists have been led to bestow their chief attention upon the result, and not upon the course of these changes. Occupied in investigating the relation between the reagents and the ultimate products of a reaction, and studying the chemical and physical properties of the thousand different substances thus produced, they are accustomed to regard the various conditions under which every chemical change takes place, and by which its amount is determined, chiefly as means to an end, as points to be attended to in a receipt for preparing one substance from another.

The object of the investigation which the authors have the honour of laying before the Royal Society in the following pages, has been to estimate quantitatively the relation of chemical change to some of these conditions. With this view they have selected for examination cases in which the change appeared to be of a simple character, and the conditions affecting it few in number, and capable of being defined.

Although unquestionably every chemical reaction is governed by certain general laws relating to the quantity of the substances partaking in it, their temperature and physical state, and the time during which they are in contact, yet the number of cases in which the investigation of these is practicable is extremely limited. In the first place, it must be possible both to start and terminate the reaction abruptly at a given moment. In the next, either some product or some residue of the action must be a substance for whose estimation exact and ready methods are known, that so the amount of change may be quantitatively determined. Lastly, all the conditions of the reaction must be measurable, or at least definable, and some of them susceptible of modification at will, that thus the influence of each may be examined.

---

* The experimental inquiries recorded in this paper were chiefly Mr. Harcourt's, the mathematical discussion is Mr. Esson's.

The first reaction chosen by us for investigation was that of permanganic acid upon oxalic acid. It is well known that when a solution of potassic permanganate is added to a solution containing oxalic acid and sulphuric acid, its red colour gradually disappears, owing to the reduction of the permanganic acid. The final result of the change is thus represented:

$$K_2 Mn_2 O_8 + 3H_2 SO_4 + 5H_2 C_2 O_4 = K_2 SO_4 + 2Mn SO_4 + 10CO_2 + 8H_2 O.$$

This reaction occurs at a temperature which is easily kept constant and can be exactly measured. It occupies, under duly arranged conditions, a convenient interval of time. The reagents and the products of the reaction are all soluble, and thus the system can quickly be made and will remain homogeneous. The reagents are readily obtained in a state of purity, and divided and measured as liquids. The reaction can be stopped abruptly, and the residual permanganic acid estimated, by adding to the solution potassic iodide and determining volumetrically the amount of iodine liberated. Lastly, no variation of light, such as occurred in the course of experimenting*, or of atmospheric pressure, or of any other condition besides those that have been named, affects the result. But the action is not chemically simple. The various complications which it exhibits will be discussed as they are revealed by successive experiments. One of these occasions the well-known change of colour from red to brown, which the liquid undergoes as the action proceeds. The manganous sulphate which is formed by the reduction of the higher oxide reacts upon the remaining permanganic acid, producing one or more intermediate oxides which combine with oxalic acid. And since the formation and reaction of manganous sulphate could not be avoided, it became necessary to include this salt among the reagents, the effect of whose variation was to be determined.

A. *Variation of Sulphuric Acid.*

The following experiments were made in order to discover the variation in the amount of chemical change due to a variation in the amount of sulphuric acid, the other conditions of the reaction being kept constant. In every experiment the solution contained $K_2 Mn_2 O_8$, *i. e.*, 316·2 parts of permanganate of potassium, $5H_2 C_2 O_4$, and $2Mn SO_4$. The absolute weight of potassic permanganate used in each experiment was ·014 gramme, the volume of the solution was 330 cub. centims., its temperature 16° C., and the time allowed to elapse between the mixture of the ingredients and the termination of the action was four minutes. The action was terminated by the sudden addition of an excess of potassic iodide, by which the remaining permanganate is instantaneously reduced. The amount of iodine set free, which had previously been proved to furnish an exact measure of the permanganate, was finally determined by means of a standard solution of sodie hyposulphite.

---

* Direct sunlight produces a great acceleration.

TABLE I.

$K_2 Mn_2 O_8 + 5 H_2 C_2 O_4 + 2 Mn S O_4 + x H_2 S O_4$.

Volume of solution 330 cub. centims. Temperature 16° C. Time 4 mins.

1. Molecules of sulphuric acid. x.	2. Cub. centims. of hyposulphite used.		3. Percentage of oxidizing residue. y.	4. Percentage of chemical change. $100-y$.
	(1)	(2)		
2	28·4	28·4	78·2	21·8
4	23·45	23·05	64·0	36·0
6	17·9	17·55	48·9	51·1
8	13	13·5	36·5	63·5
10	10·3	……	28·4	71.6
12	8·25	8·2	22·6	77·4
14	6·4	6·4	17·6	82·4
16	5·25	5·1	14·3	85·7
22	2·8	……	7·7	92·3

When no oxalic acid was taken and the whole amount of permanganate was represented by its equivalent of iodine, there were used to decolorize the solution 36·3 cub. centims. of hyposulphite.

The numbers in column 3 are obtained by making this number 100, and reducing the mean of those in column 2 to the same scale. It will be seen that the amount of chemical change occurring within the allotted time increases continually with the quantity of sulphuric acid in the solution, the effect, however, of successive increments being less and less. This relation is exhibited by the annexed curve (Plate XVII. fig. 1). In spite of the apparent simplicity of the conditions of these experiments and of the progressive variation introduced, no simple relation could be discovered between the two series of numbers. It will be shown subsequently, by the light of later experiments, that the relation between them is of a very complex character. Two molecules of manganous sulphate were added to the mixture, that the rate might not be disturbed by its gradual formation. The part played by this salt appearing particularly worthy of investigation, was made the subject of the next series of experiments.

B. *Variation of Sulphate of Manganese.*

All the conditions adopted in the first series were repeated in this, with the exception that ten molecules of sulphuric acid were used in each experiment, and the amount of manganous sulphate was varied.

TABLE II.

$$K_2 Mn_2 O_8 + 5 H_2 C_2 O_4 + 10 H_2 S O_4 + x Mn S O_4.$$

Volume of solution 330 cub. centims. Temperature 16° C. Time 4 mins.

1. Molecules of sulphate of manganese. x.	2. Cub. centims. of hyposulphite used.		3. Percentage of oxidizing residue. y.	4. Percentage of chemical change. $100-y$.
	(1)	(2)		
0·0	36·0	......	99·2	0·8
0·25	35·25	......	97·2	2·8
0·5	34·5	34·7	95·3	4·7
0·75	34·25	33·95	93·9	6·1
1·0	32·7	32·7	90·3	9·7
1·25	31·35	......	86·4	13·6
1·5	28·45	......	78·4	21·6
1·75	18·5	20·0	52·3	47·7
2·0	10·8	10·9	29·9	70·1
2·25	7·45	7·5	20·6	79·4
2·5	6·0	6·3	17·1	82·9
2·75	5·85	5·75	16·0	84·0
3·0	5·6	5·65	15·4	84·6
4·0	5·4	5·4	14·9	85·1
5·0	5·35	5·35	14·7	85·3
10·0	5·15	5·0	14·2	85·8

It appears from these experiments, the results of which are depicted (Plate XVII. fig. 2), that the effect of increasing the amount of manganous sulphate in the solution is to accelerate the action to a small extent only when the quantity added is small, but rapidly when it exceeds one molecule, until at the point where three molecules are taken, a rate is attained which is hardly increased by any further addition. This maximum rate is first reached with that quantity of manganous sulphate which is capable of reacting with the potassic permanganate to form binoxide of manganese,

$$K_2 Mn_2 O_8 + 3 Mn S O_4 + 2 H_2 O = K_2 S O_4 + 2 H_2 S O_4 + 5 Mn O_2.$$

In the succeeding experiments at least three molecules of manganous sulphate were always introduced into the solution, that the gradual formation of this salt as the reduction of the permanganate proceeds might not complicate the result. As to the manner in which manganous sulphate acts, the gradual changes which took place in the appearance of the fluid bore conclusive testimony. Though the final result, whenever not less than three molecules of this salt were present, was nearly the same, the liquid passed from a pink to a brown colour more rapidly as the quantity was increased, and with the largest proportion it became first turbid, and then comparatively clear again, before the four minutes had elapsed.

C. *Variation of Oxalic Acid.*

Two series of experiments were made in order to determine the effect of varying the proportion of oxalic acid which takes part in the reaction. In one of these only potassic permanganate, manganous sulphate, and oxalic acid were employed; in the other there was added also a constant quantity of sulphuric acid. To prevent the action being inconveniently slow, the volume of the solution was reduced to 100 cubic centimetres. The numerical results are contained in the following Tables, and are expressed by the curves in Plate XVII. figs. 3 & 4.

TABLE III.

$K_2 Mn_2 O_8 + 3 Mn S O_4 + x H_2 C_2 O_4$.

Volume of solution 100 cub. centims. Temp. 16° C. Time 3 mins.

1. Molecules of oxalic acid. x.	2. Cub. centims. of hyposulphite.	3. Percentage of oxidizing residue. y.	4. Percentage of chemical change. $100-y$.
0	36·3	100·0	0·0
1	29·85	82·2	17·8
2	25·95	71·5	28·5
3	23·5	64·7	35·3
4	21·85	60·2	39·8
5	20·5	56·5	43·5
6	21·0	57·9	42·1
7	23·35	64·3	35·7
8	31·85	87·8	12·2
9	33·4	92·0	8·0
10	33·55	92·4	7·6
11	33·8	93·1	6·9
15	33·85	93·3	6·7
20	33·6	92·6	7·4
30	33·5	92·3	7·7
50	31·95	88·0	12·0
100	29·45	81·8	18·2

TABLE IV.

$K_2 Mn_2 O_8 + 3 Mn S O_4 + 15 H_2 S O_4 + x H_2 C_2 O_4$.

Volume of solution 100 cub. centims. Temperature 16° C. Time 3 mins.

1. Molecules of oxalic acid. x.	2. Cub. centims. of hyposulphite.	3. Percentage of residue. y.	4. Percentage of chemical change. $100-y$.
0	36·1	100·0	0·0
1	28·7	79·5	20·5
2	20·85	57·7	42·3
3	13·4	37·1	62·9
4	8·0	22·2	77·8
5	4·55	12·6	87·4
6	3·0	8·3	91·7
7	5·5	15·2	84·8
8	13·85	38·4	61·6
9	26·55	73·6	26·4
10	29·95	83·0	17·0
11	31·25	86·6	13·4
12	31·85	88·2	11·8
15	32·6	90·3	9·7
20	32·95	91·3	8·7
30	32·85	91·0	9·0

It will be seen that in both cases the quantity of permanganate reduced in three minutes increases with the proportion of oxalic acid up to a certain point; it then diminishes again until another point is reached; after which further additions of oxalic acid produce once more a very gradual acceleration. The first part of this result is readily intelligible. The rate at which the reduction proceeds is greater with a larger amount of the reducing agent. But why does a still larger amount produce an opposite effect? The explanation is to be found no doubt in another circumstance by which this reaction is complicated. When solutions of manganous sulphate and potassic permanganate are mixed, a precipitate of hydrated manganic binoxide is produced, which soon separates from the liquid, leaving it colourless if the manganous salt were in excess*. The presence of a sufficient quantity of oxalic acid prevents this precipitation; a clear brown liquid is formed whose colour very slowly fades, the reduction in a cold and dilute solution occupying many hours. This solution, like that of cupric oxide in potash containing a reducing substance, depends no doubt upon a chemical combination which precedes the mutual action of oxidation and reduction. Probably the brown liquid contains oxalate of manganic binoxide. In the experiments with oxalic acid only, the maximum action in three minutes occurs very near that point at which the amount of oxalic acid present is five molecules, or the quantity which the measure of permanganic acid can oxidize. If, as the experiments with manganous sulphate appear to prove, the first stage of the reaction consists in the formation of manganic binoxide, this maximum action occurs with one molecule of binoxide and one of oxalic acid. The subsequent minimum again nearly coincides with that point at which ten molecules of oxalic acid have been added for one of permanganate, or two for one of binoxide. It was also observed that whenever a less amount than this was taken, the liquid became turbid, but with this or any larger amount it remained clear. According to analogy, oxalate of manganic binoxide should have the formula $Mn\,O_2$, $2\,C_2\,O_3$, or $Mn\,C_4\,O_8$. For its formation two molecules of oxalic acid are required. The final action, when not less than two molecules of oxalic acid have been taken, may therefore be thus represented:

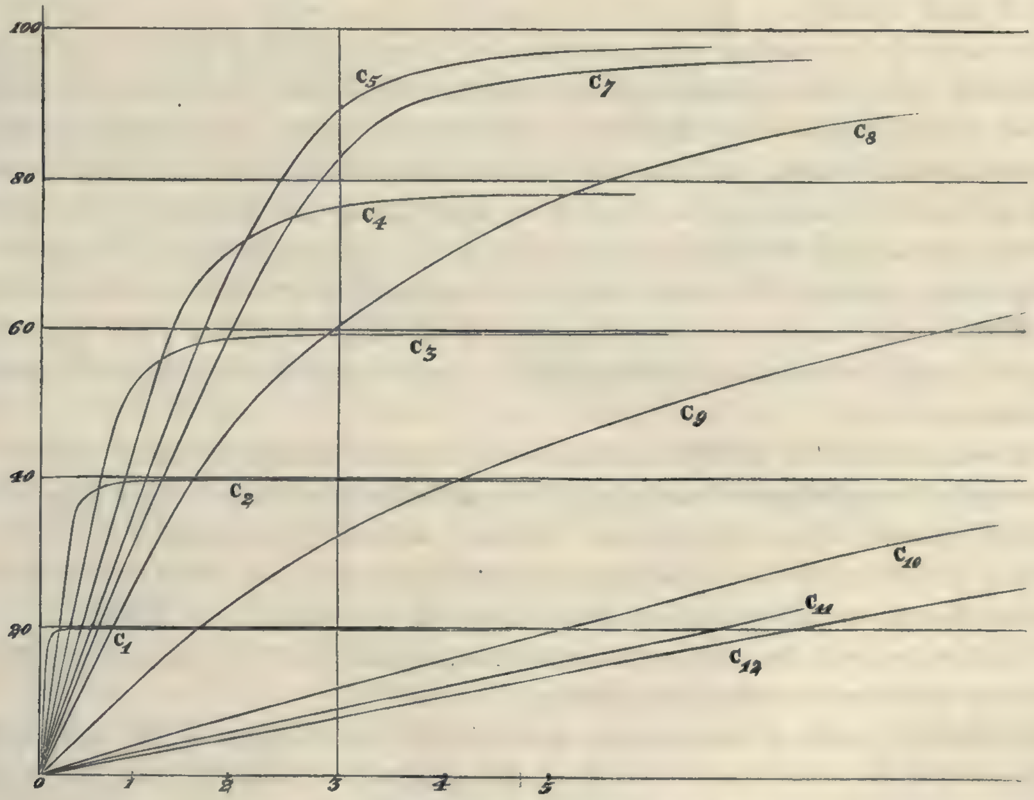
$$(1)\quad Mn\,O_2+2\,H_2\,C_2\,O_4=2\,H_2\,O+Mn\,C_4\,O_8.$$
$$(2)\quad Mn\,C_4\,O_8\quad=Mn\,C_2\,O_4+2\,C\,O_2.$$

The decomposition of this salt takes place more slowly than does the oxidation of oxalic acid by free binoxide of manganese; it is accelerated by the presence of sulphuric acid, or of a great excess of oxalic acid.

In the second series of experiments, in which sulphuric acid was introduced, the amount of action is at first proportional to the amount of oxalic acid taken, for within the allotted three minutes the whole is oxidized. Afterwards the total reduction effected within this time is still increased by the addition of a fourth and fifth and even of a sixth molecule; but the increase is no longer in direct proportion, but in a less ratio. The explanation already suggested appears to be in accordance with all the phenomena both of this and of the first series. The rate at which a given amount of oxalic acid is oxidized diminishes as the total amount present increases up to that point at which enough has been added to convert the potassic permanganate and manganous sulphate into oxalate of manganic binoxide and a potassium salt. With one molecule the rate at which its oxidation proceeds is very great, but when it is complete, the percentage of chemical change cannot exceed twenty. Accordingly it attains this limit in the second series, and nearly approaches it in the first. With two molecules the rate is less, and still less with three, but the proportion oxidized in any time is a less proportion of a larger quantity. When five molecules have been added, the total amount of chemical change possible cannot be increased, since this quantity is sufficient to reduce the whole of the permanganate. Consequently the amount oxidized in any time is thenceforward a less proportion of the same quantity. The annexed diagram, in which the course of each experiment is represented by a separate curve having for its asymptote a line parallel to the axis of x at a distance representing the total amount of chemical change possible after the lapse of any length of time, may serve for illustration.

---

* In this case the precipitate consists of $5\,Mn\,O_2$, $Mn\,O$.—GORGEU, 'Ann. de Chim. et de Phys.' 3rd series, vol. lxvi. p. 153.



x = time; y = percentage of chemical change; C_1, C_2, ... C_{12} curves representing the action with 1, 2, ... 12 molecules of oxalic acid.

The experimental numbers in the two Tables are to be regarded as a series of measurements of the distance of a point on each curve from the axis of x, along an ordinate whose distance from the axis of y represents an interval of three minutes.

Sulphuric acid appears to accelerate the reaction in two ways. First, it promotes the action of manganic binoxide on oxalic acid; and secondly, it retards the formation of the comparatively stable compound, which in its absence is at once produced on mixing the three other ingredients. This is shown by the persistency of the red colour of permanganic acid in a mixture containing a large proportion of sulphuric acid. To the former cause principally must be attributed the greater rate of change throughout the second series, and to the latter the circumstance that in this case the maximum action occurs with rather more than five molecules, and the subsequent minimum with more than ten. It seems probable that with a large excess of sulphuric acid the rate at which the reduction proceeds would be found to vary directly with the quantity of oxalic acid, according to the law which appears to exist in other similar cases.

D. *Variation of Time.*

One of the conditions which has been kept constant hitherto, is the time during which the reaction has been allowed to proceed. But in order to discover the exact effect of each chemical or physical variation, it is necessary to be acquainted with the whole course of the reaction, and not merely with the amount of change accomplished under each set of circumstances during one interval of time. Now, by performing a number of experiments only differing one from another in the period which is allowed to elapse between starting and stopping the reaction, we may trace its course with any required degree of minuteness. And if we can discover the relation of the series of numbers representing the duration of the several experiments to those representing the corresponding amounts of chemical change, an expression may be thence deduced for the rate at which the reaction is proceeding at a given time, or with a given quantity of substance, and a comparison made between the rates derived from different series of experiments.

If it were possible for all the conditions of a chemical change to remain constant, if, for example, the substances reacting could be added in proportion as they disappeared, and those formed either were without influence or could be removed, the effect of a variation of time might be confidently predicted. In such a case the total amount of chemical change would be directly proportional to the duration of the action. But where one or more of the substances diminishes in quantity as the change proceeds, the relation is no longer of this simple character.

The following series of experiments, in which only the duration of the reaction was varied, had for its object the discovery of this relation. The various substances were employed in the proportions in which they react with one another, except the sulphuric acid, of which a double portion was taken. After the other solutions had been mixed and brought to the right volume and temperature, the measure of potassic permanganate, 0·014 grm. in 10 cub. centims. of water, was added and rapidly mixed with the rest. The moment of its addition was noted, and when the proper interval had elapsed an excess of potassic iodide was thrown in. The amount of iodine liberated was then determined.

TABLE V.

$K_2 Mn_2 O_8 + 3 Mn S O_4 + 6 H_2 S O_4 + 5 H_2 C_2 O_4$.

Volume of solution 330 cub. centims. Temp. 16° C. Time x mins.

1. Duration of experiment, in minutes. x.	2. Percentage of oxidizing residue. y.	3. Percentage of chemical change. $100-y$.
1	95·6	4·4
2	83·2	16·8
3	66·8	33·2
4	55·2	44·8
5	44·5	55·5
6	36·3	63·7
7	31·6	68·4
8	27·2	72·8
9	25·0	75·0
10	22·5	77·5
15	13·5	86·5
17	11·8	88·2

This series of determinations may be regarded as exhibiting the course of a single experiment in which the reaction is allowed to proceed during seventeen minutes. Of a hundred parts of the oxidizing and reducing substances (or transferable oxygen, or chemical energy) originally present, there remain after one minute 95·6 parts, after two minutes 83·2 parts, and so on. Throughout the middle part of the course of this experiment, from the end of the fourth to the end at any rate of the tenth minute of its progress, a relation exists between the corresponding numbers in the first and second columns which strikes the eye at once. Their product is a constant quantity. The divergence of the results for the fifteenth and seventeenth minutes is probably due to an experimental error, committed either in determining the rather small amount of residue, or in the measurement of the proportional quantities of the two principal reagents; such an error would affect chiefly the later stages of the experiment, the ratio of the two substances which should be constant changing slowly at first and afterwards more rapidly. But the divergence of the result in the earlier part of the experiment is much more considerable, and shows unmistakeably that, until the reaction has advanced a certain distance, it does not follow the hyperbola which correctly represents the remainder of its course. The same fact, it will be seen, reappears in every similar series of experiments. Its cause was for a long time obscure, and the authors were driven to discard this relation, which appeared only to hold good for part of their results, and to be inconsistent with others of equal authority. Later experiments, however, have established the reality of this relation, and led to the discovery of the cause of divergence.

The reaction under consideration has already been shown to occur in two stages, in the first of which manganic binoxide is produced by the reaction of permanganic acid on manganous sulphate, and in the second of which it is reduced by oxalic acid, after previous combination, when that acid is present in excess.

$$(1)\ K_2Mn_2O_8+3MnSO_4+2H_2O=K_2SO_4+2H_2SO_4+5MnO_2.$$

$$(2)\ MnO_2+H_2SO_4+H_2C_2O_4=MnSO_4+2H_2O+2CO_2.$$

Unfortunately both these reactions belong to the class, comparatively rare in inorganic chemistry, of slow actions. If either of them occurred very rapidly as compared with the other, the curve representing the reaction of proportional quantities would doubtless be a hyperbola from its starting-point. As it is, the first action takes place more rapidly than the second, their relative rates varying, however, according to the conditions of each experiment. In the present case the first action has nearly attained its limit at the end of four minutes, and thenceforward the only change taking place is that which the second equation expresses. After this time the simple law already enunciated holds good, and the residues become inversely proportional to the duration of the action. In this case the actual moment of starting the experiment happens, through the complication of the double action, to be the true epoch from which to reckon its duration. But in other cases it is not so: the zero of the series of numbers representing the time should correspond to an infinite amount of the active substances, and not to 100 parts. The full discussion of the significance of this relation, and of the course of the reaction when the two changes are occurring simultaneously, is reserved until the entire series of experiments has been brought forward; but it may be shown that the inverse proportionality of the residue to the time depends upon a law the generality of which we hope hereafter to establish, namely, that the total amount of chemical change varies directly with that of each of the substances partaking in it.

Let $x=$ the duration of the action dated from a point such that when $x=0$, $y=\infty$; and let $y=$ the number of molecules of the oxidizing and reducing substances present in the solution at the time x. Then $\frac{dy}{dx}$ is the amount of change in a unit of time, and this is proportional to y^2, since both substances are changing, and the amount of change varies directly with the quantity of each of them. Hence we have the equation

$$\frac{dy}{dx}\propto -y^2=-\frac{1}{k}\cdot y^2,$$

which gives

$$xy=k,\ \text{or}\ y\propto\frac{1}{x}.$$

The following Table contains the results of three similar series of experiments, differing from the last and from one another only in respect of the quantity of sulphuric acid used in each.

TABLE VI.

$$K_2 Mn_2 O_8 + 3 Mn S O_4 + 5 H_2 C_2 O_4 + n H_2 S O_4.$$

Volume of solution 330 cub. centims. Temperature 16° C. Time x mins.

Duration of experiment, in minutes. x.	Percentage of oxidizing residue.		
	$n=12$. y.	$n=18$. y.	$n=24$. y.
1	94·5	93·3	
2	76·2	73·2	
3	52·0	39·6	30·8
4	37·8	24·3	17·9
5	28·5	18·6	13·1
6	23·3	14·5	10·4
7	19·7	12·0	7·6
8	16·7	9·6	
9	14·5	7·6	

These numbers present a less obvious relation than those of the first series, but it may be observed in all, after the fourth minute, that if the numbers representing the time, minus about one minute, be multiplied into the corresponding amounts of residue, the product is approximately a constant quantity, $(x-x_0)y=k$. But in fact each successive series is less and less conformable to this relation. Probably the increase in the amount of sulphuric acid produces this effect by diminishing the disproportion between the two rates before mentioned, for its action is to retard the formation of manganic binoxide, and to hasten its reduction by oxalic acid.

With a smaller quantity of sulphuric acid and a larger quantity of manganous sulphate more satisfactory results were obtained, but it was not found possible, when only a proportional quantity of oxalic acid was employed, to hinder the solution from becoming turbid through separation of manganic binoxide. The use of a large volume of water prevents the occurrence of this turbidity, but impairs too far the accuracy of the subsequent determinations. The series of experiments recorded in the following Table traces the course of the reaction with an excess of manganous sulphate, and proportional quantities of each of the other substances, through its entire length.

TABLE VII.

$$K_2 Mn_2 O_8 + 15 Mn S O_4 + 3 H_2 S O_4 + 5 H_2 C_2 O_4.$$

Volume of solution 100 cub. centims. Temperature 16° C. Time x mins.

1. Duration of experiment, in minutes. x.	2. Percentage of oxidizing residue. y.	3. Values of y, calculated from $(x+·1)y=157$.	4. Percentage of chemical change. $100-y$.
0·25	91·0	......	9·0
0·5	81·0	......	19·0
1	65·8	......	34·2
2	51·9	......	48·1
3	42·4	......	57·6
4	35·4	......	64·6
5	29·8	......	70·2
6	25·7	25·7	74·3
7	22·2	22·1	77·8
8	19·4	19·4	80·6
9	17·3	17·3	82·7
10	15·5	15·5	84·5
15	10·4	10·4	89·6
20	7·8	7·8	92·2
30	5·5	5·2	94·5
40	4·4	3·9	95·6

It will be seen that after six minutes the residues still unreduced are inversely proportional to the time during which the action has continued. In the earlier stages of the reaction its rate follows a less simple law, probably for the reason already stated—the gradual though relatively rapid action of permanganic acid on the excess of manganous salt. The actual modification thus introduced will be considered subsequently, and it will be shown that, from an equation in which account is taken of this action, the earlier numbers may be calculated as well as the later. A curve representing this series will be found in Plate XVII. fig. 6. The duration of the reaction is measured along the axis of x, and the remaining chemical energy along the axis of y. The former is an asymptote of the curve: the absolute disappearance of the oxidizing and reducing substances requires theoretically an infinite time. The other asymptote falls just beyond the axis of y: no amount of binoxide can be taken so great, as that with it this reaction should proceed for six minutes and six seconds, and still leave a residue of 25·7 parts. The best equation for the lower part of this curve is $(x+0{\cdot}1)y=157$.

In the foregoing series of experiments the principal reagents have been employed in the proportions in which they act one upon another, that so their ratio might remain constant throughout. The same result may be approximately attained by taking very large quantities of all the reagents except one, or at least such quantities that the alteration which they undergo in the course of the experiment can produce no appreciable effect upon the rate at which the chemical change is proceeding. It is most convenient to select the substance of which the residue can be determined as that of which a relatively small quantity is to be employed. The conditions of the reaction under these circumstances are indeed simpler than in the former case; for then each of the substances acting on one another is diminished, and thus two or more variations are made simultaneously, while in this case a single substance gradually disappears, all around it remaining unchanged.

Accordingly solutions were prepared of the different reagents, of such a strength as that one measure of each should contain a large excess, as compared with the amount contained in one measure of the standard solution of potassic permanganate.

The actual quantities used in each experiment were the following:—

	Potassic permanganate.	Manganous sulphate.	Oxalic acid.	Sulphuric acid (one unit).	Water.
Weight in grammes ...	0·015	0·1	0·648	0·352	200·0
Molecules	1·0	13·9	108·4	75·8	
Proportional parts	1·0	4·6	21·7	25·3	

By proportional parts are meant those quantities which react according to the equations before written.

The method of performing these experiments underwent various modifications during their course. That which was finally adopted for this and the concluding set may be here briefly described. Different series of experiments differed from one another only in the proportion of sulphuric acid employed, and the several experiments of the same series differed only in the time during which the reaction was allowed to proceed. One description therefore will serve for all; and to render this description more precise, let it refer particularly to the eighth series of the present set. In the first place, a mixture was made to serve for all the experiments of the series by bringing together in a large flask 200 cub. centims. of the standard solutions of oxalic acid and manganous sulphate, each of these solutions containing in 10 cub. centims. the amount required for one experiment, 400 cub. centims. of standard sulphuric acid containing in 10 cub. centims. four units, and 3000 cub. centims. of water. This mixture was exactly divided by means of a narrow-necked flask marked to hold 190 cub. centims., among twenty flasks each of about 300 cub. centims. capacity. One of these was taken and its contents brought to a temperature of 16° C. It was then placed in an arrangement for keeping the temperature constant, consisting of an inner and outer casing, supported over a lamp, the interval between which was filled with water at a temperature of 16°. The interior of the inner casing was lined with cotton-wool, and it was provided with a lid similarly lined, which could be slipt over the neck of the flask. A delicate thermometer passed into the fluid through a disk of cardboard, by which the flask's mouth was closed. The standard solution of potassic permanganate was contained in a bottle encased in the same manner, and was maintained at the same temperature. A clock beating seconds served to measure the duration of the experiments. When the thermometer stood constantly at 16°, a 10 cub. centims. pipette was charged with the permanganate solution, the flask was removed for a moment from its receptacle, and the liquid in the pipette allowed to run into it, starting by beat of the clock at the beginning of a minute. By shaking round the flask as the liquid entered, the whole was perfectly mixed at the end of about ten seconds. If the temperature had suffered any disturbance, it was raised or lowered by the application of the hand or of a damp cloth. The flask was then replaced, and required but little attention until the time for stopping the reaction approached.

For determining the residue, we have made use of a standard solution of sodic hyposulphite. This reagent, according to our experience, is liable to a gradual alteration by which its reducing power is slightly diminished, a few particles of sulphur being at the same time separated from it. The addition of a minute quantity of caustic soda prevents the occurrence of this change, and renders the value of the solution absolutely constant. Just before the allotted time had elapsed a measure of potassic iodide solution, containing rather more than enough to reduce the permanganate originally taken, was poured into a test-tube; the flask was then removed from its casing, and at the proper moment the contents of the test-tube were discharged into it. By a single rapid shake the iodide is diffused through the liquid, and all the molecules of peroxide which have escaped the slow action of oxalic acid are instantaneously reduced, leaving in their stead so many molecules of iodine, which are without action on any ingredient of the solution and can therefore be estimated at leisure. By using a very dilute solution of hyposulphite, and a freshly prepared and filtered solution of starch, the subsequent determination may be performed with a high degree of accuracy. Some of the measured quantities of the mixed solution were always reserved for a repetition of previous experiments; in several instances the whole series was performed twice. In these latter sets the readings of the burette, after two similar experiments, seldom differed by more than 0·15 cub. centim. From time to time the value of the measure of permanganate was taken in terms of the solution of hyposulphite, and the numbers given in the Tables as the percentage of residue are obtained by multiplying the actual readings on the burette by 100, and dividing by this number.

The following Table contains the results of fifteen series of experiments thus conducted. Their object was twofold, to establish by a sufficient induction the true course of the reaction, and to discover by a comparison of the different series the relation between the rate of change and the quantity of sulphuric acid employed. The curves representing this series of experiments will be found on Plate XVIII. fig. 1.

Table VIII.

$$K_2 Mn_2 O_8 + 14 Mn S O_4 + 108 H_2 C_2 O_4 + n(76 H_2 S O_4).$$

Volume of solution 200 cub. centims. Temperature 16° C. Time x mins.

Duration of experiment, in minutes. x.	Percentage of oxidizing residue.						
	$n=1$. y.	$n=2$. y.	$n=3$. y.	$n=4$. y.	$n=5$. y.	$n=6$. y.	$n=7$. y.
½	......	......	......	92·9	91·4	......	88·7
1	94·4	91·9	89·2	86·8	83·1	81·2	79·1
1½	......	......	......	81·6	76·9	73·4	69·6
2	90·4	86·3	81·1	76·8	70·6	66·4	61·6
2½	......	......	......	......	......	......	54·9
3	86·7	80·0	73·5	67·2	59·8	54·7	49·0
3½	......	......	......	......	......	......	43·9
4	82·3	74·6	66·7	59·1	51·5	45·3	39·5
5	78·8	......	60·9	52·6	44·4	37·9	32·4
6	75·5	65·2	55·3	47·0	38·5	31·9	26·9
7	71·8	......	50·6	41·8	33·4	27·7	22·2
8	68·4	58·1	46·3	37·3	29·7	23·3	
9	......	......	42·5	......	26·4	19·8	
10	62·1						

TABLE VIII. (continued).

Duration of experiment, in minutes. x.	Percentage of oxidizing residue.						
	$n=8$. y.	$n=9$. y.	$n=10$. y.	$n=11$. y.	$n=12$. y.	$n=13$. y.	$n=16$. y.
½	……	……	84·5				
1	74·5	73·3	70·4	67·4	64·1	61·6	57·2
1½	64·5	……	58·5	54·8	51·4	47·3	41·4
2	56·3	53·0	48·7	44·9	40·8	37·3	30·7
2½	49·2	43·7	41·0	36·9	32·5	29·2	23·1
3	43·2	38·8	34·2	30·5	26·8	23·3	17·5
3½	38·1	33·8	29·2	25·4	21·6	18·7	13·9
4	33·6	29·3	25·2	21·6	17·8	15·5	11·2
4½	……	……	21·7	18·1	15·1	12·9	9·2
5	27·2	22·6	18·6	15·5	13·0	……	7·5
6	21·6	……	14·5	……	9·7	8·0	5·5
8	……	……	……	……	……	4·4	
9	12·3	……	……	……	5·9		

It will be seen that by varying the quantity of sulphuric acid from 25 to 400 proportional parts, the reaction is caused to take place with very different velocities. Under the conditions of the last set of experiments more work is done in one minute than is done in ten minutes under the conditions of the first set. In how orderly a manner the amount of residue diminishes as the reaction proceeds, and the rate of change increases with the proportion of sulphuric acid, is shown by the series of curves on Plate XVIII. fig. 1, corresponding to this Table. Guided by the empirical relation which we had observed in the case of the reaction of proportional quantities, we endeavoured to apply the hyperbola to these curves also. It soon became evident, especially from those experiments in which the reaction proceeded rapidly and was traced through a greater length, that the rectangular hyperbola was not applicable. A hyperbola with an oblique asymptote corresponded much more nearly to our experimental lines, and a number of equations of the form $y^2+axy-by=c$ were obtained, which gave values of y nearly agreeing with those which had been found. But after calculating the constants of this equation for each series of experiments, we observed, 1st, that the earlier and later numbers never agreed quite so well as the rest, the disagreement with the best possible equation at the two extremes generally rather exceeding the probable error of experiment; 2ndly, that when a curve was produced upwards, as could be done by repeating the series with a larger quantity of permanganate, the divergence became much greater; and 3rdly, that instead of the actual numbers falling in an irregular manner above and below those calculated from the equations,—as was to be expected if experimental error alone were the cause of difference,—a regular rise and fall was perceptible, the calculated numbers being in every case lower than the first observation or two, then higher than the two or three following, then lower again for four or five consecutively, and finally rising once more above them. Consequently these equations could not be accepted as expressing truly the course of the reaction, and it was therefore vain to inquire how their constants were related to the number of units of sulphuric acid employed. Some other expression for the course of the reaction had to be sought, and a consideration of the circumstances under which the reaction now takes place furnished the needful clue.

If any quantity of a substance be placed under conditions under which it gradually undergoes a change, and if both the conditions and the quantity of the substance be by a due system of compensation kept constant, the rate of change will be uniform; that is to say, the amount of substance which disappears in a unit of time will be always the same. This amount therefore, for any particular unit of time, is a certain fixed proportion of the total quantity undergoing change. If, now, the system of compensation be so far disturbed as that while other conditions remain the same the quantity of substance be allowed to diminish, it seems probable that the total amount of change occurring at any moment will be proportional to the quantity of substance then remaining.

Adopting this hypothesis, the law of connexion between the quantity of substance remaining at any time, and the time during which the change has proceeded, may be found in the following way:—

Let y represent the amount of substance remaining after the change has proceeded for a time x, and let dy be the diminution of the substance during an infinitesimal time dx, then $\frac{dy}{dx}$ represents the amount of substance which disappears in a unit of time; and this amount is by the hypothesis proportional to the quantity of substance remaining; so that we have the equation

$$\frac{dy}{dx}=-\alpha y,$$

which gives

$$y=ae^{-\alpha x},$$

where a is the quantity of substance at the commencement of the change.

This equation expresses the fact that the quantities of substance remaining after a series of intervals of time increasing in arithmetical progression, form a series in geometrical progression. After the intervals 0, 1, 2, 3, ... minutes, the quantities of substance remaining are

$$a, \quad ae^{-\alpha}, \quad ae^{-2\alpha}, \quad ae^{-3\alpha}, \quad \ldots,$$

a geometric series of which the ratio is $e^{-\alpha}$. The curve which expresses this relation between x and y is a logarithmic curve.

As the actual determinations of the oxidizing residue had been made at equal intervals of time, it was an easy matter to test the applicability of this hypothesis. It appeared that although these numbers were in most cases nearly in geometrical progression through a considerable range, they were not so throughout, and the values of y calculated on this hypothesis differed more from the experimental values than those before obtained from the equation of an oblique hyperbola. A single experiment, however, made at the close of this series, in which no sulphuric acid was taken, showed that the relation indicated by theory did, under some circumstances, actually hold good. The numerical results of this experiment are compared below with the values of y calculated from the equation $y=94·8(·974)^x$, and are represented by a curve on Plate XVII. fig. 5.

TABLE IX.

$K_2Mn_2O_8+14MnSO_4+108H_2C_2O_4$.

Volume of solution 200 cub. centims. Temperature 16° C. Time x mins.

Duration of experiment, in minutes. x.	Oxidizing residue.		Duration of experiment, in minutes. x.	Oxidizing residue.	
	Found. y.	Calculated. y.		Found. y.	Calculated. y.
2	94·8	94·8	31	44·0	44·0
5	87·9	87·6	35	39·1	39·6
8	81·3	80·9	44	31·6	31·2
11	74·9	74·7	47	28·3	28·8
14	68·7	69·0	53	24·2	24·6
17	64·0	63·7	61	20·2	19·9
27	49·3	48·9	68	17·0	16·5

Generally the reaction appeared to proceed more slowly in its later as compared with its earlier stages than on this hypothesis it ought. It seemed possible that this might arise from the excess of the various reagents employed not having been sufficient to prevent the action producing a sensible alteration in the nature of the solution, and thus affecting the rate; for unless the amount of each of the other substances be so great as compared with that whose rate of diminution is measured that the quantity subtracted from or added to them is relatively insignificant, the simplicity of the case under examination is no longer ensured. Accordingly a second set of experiments was made, in which, the amount of permanganate employed being the same, a still larger proportion was used of the other reagents; and by making two preliminary series of experiments, in one of which the same quantity was taken at the beginning of the reaction as had been present in the other at the end, namely, 99 proportional parts of sulphuric acid and oxalic acid, instead of 100 of each, and 11 parts of manganous sulphate, instead of 10, it was proved absolutely that these changes did not affect the rate, for the numbers of the two series were nearly identical.

The numerical results of this set are contained in the following Table, and are expressed by the curves (Plate XVIII. fig. 2).

TABLE X.

$K_2 Mn_2 O_8 + 30 Mn S O_4 + 500 H_2 C_2 O_4 + n(300 H_2 S O_4)$.

Volume of solution 200 cub. centims. Temp. 17° C. Time x mins.

Duration of experiment, in minutes. x.	Percentage of oxidizing residue.					
	$n=1$. y.	$n=3$. y.	$n=4$. y.	$n=5$. y.	$n=8$. y.	$n=10$. y.
1	......	87·9	82·8	77·4	60·0	48·2
1½	......	......	......	......	45·9	
2	92·9	77·3	......	59·7	35·9	23·9
2½	......	......	......	......	28·0	
3	......	67·7	56·2	45·7	22·6	13·5
3½	......	......	......	......	18·3	
4	84·5	58·5	......	36·0	15·4	8·3
4½	......	......	......	......	12·7	
5	......	51·4	38·6	......	10·5	5·1
5½	......	......	......	......	9·1	
6	76·5	......	......	22·7		
7	......	39·4	26·8	17·9		
8	68·9	......	......	14·7		
9	......	30·1	18·7			
10	61·9	......	......	9·2		
11	......	22·8	13·1			
12	54·9	......	......	5·5		
13	......	17·2	9·2			
14	48·9	......	......	4·4		
15	......	13·4	6·7			
17	......	10·3	4·1			
18	37·8					
19	......	7·7				
22	30·0					
23	......	4·3				
26	24·4					
30	17·8					
34	14·0					
40	10·4					
46	6·8					

Of these experiments three series, those with 300, 400, and 500 proportional parts of sulphuric acid, give numbers which conform approximately to the relation $y=ae^{-\alpha x}$, but the more rapid action which occurs with 800 and with 1000 parts of acid cannot be expressed by an equation of this form. The excess of the other reagents over that which suffers reduction is as great, and that of the sulphuric acid greater, in these than in the first experiments. Some other cause than a change in the medium in which the gradual action takes place must therefore produce this departure from the theoretical result. Comparing the former set of determinations with these, it appears also that the divergence in both is of the same kind, and therefore presumably due to the same cause. In both the ratio of the descending series gradually diminishes. The true reason is probably to be found in the fact that more than one gradual change takes place under the circumstances of our experiments, and that we have only been able to measure the total result. Our attempts to separate these actions and investigate them singly have been unsuccessful, and we have been compelled in consequence to leave the examination of this reaction, and seek for a simpler case of chemical change. We may, however, in concluding this part of our work, show, first, from independent experiments, that we have probably been dealing with more than one reaction; and secondly, that numbers agreeing with those of all the experimental series may be calculated from equations expressing the hypothesis that three simultaneous changes take place.

In determining the amount of free iodine at the end of each experiment, some difficulty was experienced from the rapid return of the blue colour after its removal by the last drop of hyposulphite, and it was found necessary to allow as short a time as possible to elapse between the addition of potassic iodide and the determination. The conditions of this gradual oxidation of hydriodic acid were afterwards examined, and it was found that the action was due neither to the oxalic acid nor the manganous sulphate, nor any other of the reagents employed, but occurred only in the fluid in which the gradual oxidation of oxalic acid had taken place, and that moreover the rate of its occurrence depended upon the quantity of oxalic acid thus oxidized. Some experiments were made in which this secondary oxidation was allowed to reach its limit. The action of the air, which in presence of manganous salt, when the solution is let stand for many hours, is apt to be considerable, was rendered as small as possible by boiling out the water used and keeping the liquid under carbonic acid; a correction for it was also obtained from a comparative experiment. It appeared that the secondary oxidation did not exceed one-sixth of the primary, and bore to it often a still smaller proportion, while at the same time its amount was always sufficient to leave no doubt as to the reality of the phenomenon. The available oxygen of the permanganate is thus finally distributed in two ways, part of it remaining in a form in which it acts gradually on hydriodic acid, and another larger part having no such action. What oxidizing substance the colourless solution still contains, whether a less reducible salt of manganese, or some compound produced, as is most likely, by the gradual oxidation of oxalic acid, we do not know; but the fact that some substance is formed besides a manganous salt, carbonic acid, and water, is certain. If, however, two products, or any number of different products, are formed by the action, according to different equations, of one oxidizing substance—binoxide of manganese, for example,—the quantities of this substance remaining after equal intervals of time should still be in geometric progression; for the amounts of each of the products which is formed at any given time is proportional to the whole amount of binoxide present in solution at that time, and in consequence the amount of binoxide which disappears owing to the formation of each of the products is also proportional to the whole amount of binoxide present.

Let $d_1y, d_2y, \ldots d_ny$ be the amounts of binoxide which disappear during an infinitesimal time dx, owing to the formation of n different products, then $\frac{d_1y}{dx}, \frac{d_2y}{dx}, \cdots \frac{d_ny}{dx}$ are the amounts of binoxide which disappear in a unit of time owing to their formation, and each of these is proportional to the whole amount y of binoxide present at a time x;

hence

$$\frac{d_1y}{dx}=-\alpha_1y,\ \frac{d_2y}{dx}=-\alpha_2y,\ldots\frac{d_ny}{dx}=-\alpha_ny;$$

but if dy is the whole amount of binoxide which disappears in the time dx, we have

$$dy=d_1y+d_2y+\ldots+d_ny,$$

and therefore

$$\frac{dy}{dx}=-(\alpha_1+\alpha_2+\ldots+\alpha_n)y,$$

or

$$y=ae^{-(\alpha_1+\alpha_2+\ldots+\alpha_n)x},$$

a logarithmic curve of the same type as that obtained in the case in which only one product is formed.

But since the proportions of the reagents and all other conditions of the reaction have been kept rigorously constant, we may presume that between any two reagents only one reaction occurs. If, therefore, oxalic acid yields both the normal products of its oxidation, carbonic acid and water, and also the substance, whatever it may be, which acts slowly on hydriodic acid, it is probable that it is oxidized by more than one reagent. The following experiments supply some further evidence that oxalic acid may hold dissolved two distinct manganic oxides, and be attacked by them at different rates; or—if, as we have supposed, solution here is due to combination—that two manganic oxalates may be formed whose rates of decomposition are different.

A solution was prepared of manganous-manganic sulphate by dissolving a quantity of manganous sulphate in dilute sulphuric acid, and saturating the liquid with hydrated manganic binoxide. The brown precipitate dissolves slowly and sparingly, forming a deep-red solution, which is completely decomposed by the addition of a sufficient quantity of water. A second solution was made of potassic permanganate of equal oxidizing power when measured by hydriodic acid. The rate at which each was reduced by oxalic acid in presence of equal quantities of manganous sulphate and sulphuric acid was determined, and the two rates found to be very nearly the same. A third series of determinations was made under the same conditions, excepting that no manganous sulphate was taken, with hydrated binoxide of manganese suspended in so much water as made a measure of it equivalent to a measure of the former solutions. For half a minute, until the binoxide was dissolved, the action took place rapidly; but when the liquid became clear, it proceeded more slowly for an equal amount of oxidizing residue than in the other solutions. This solution, therefore, differs from the former, which so far resemble one another, both in appearance and in rate of decomposition, as to render it likely that the chief agent is in both cases the same.

The direct action of permanganic acid on oxalic acid at a temperature of 16° or 17° is very gradual; perhaps if every trace of lower oxides of manganese and of other reducing agents than oxalic acid could be excluded, no action whatever would take place. But whether this be so or not, it may certainly be disregarded in comparison with the almost instantaneous reaction between permanganic acid and manganous salt; for when the two solutions are mixed, the deep-red colour of the former is at once destroyed and the liquid becomes dark brown. The action of these two substances under constant conditions takes place presumably according to but one equation, and gives rise to but one oxidized product. From the results of our experiments on the "Variation of Manganous Sulphate," p. 195, and the reaction of the two substances when oxalic acid is not present, this product appears to be manganic binoxide. But in the experiment just related with the three equivalent solutions, the liquid produced by acting on permanganate with a great excess of manganous sulphate nearly identified itself by its rate of decomposition with that containing the salt of the proto-sesquioxide, while it differed in this respect from that into which binoxide had been introduced.

The account of the changes occurring under the circumstances of the two sets of experiments, Tables IX. and X., to which these observations appear to lead, is the following.

By the reaction of permanganic acid on a great excess of manganous sulphate there is formed at once manganic binoxide; we may therefore consider this oxide to be contained in the liquid at the moment of starting the reaction. It finds itself in presence of two substances, both of which act gradually upon it, oxalic acid and manganous sulphate, the latter producing an intermediate oxide, probably the proto-sesquioxide, which is also reducible by oxalic acid. It is possible that other oxides besides these may be formed, but it is almost certain from our experimental results that the action is not more simple than this. At the end of each experiment both these oxides are alike instantaneously reduced by hydriodic acid, and thus measured conjointly.

A mathematical discussion of various theoretical points that have been raised in the course of our experiments is appended to this account of them. It is there shown that the equation embodying the above hypothesis is

$$y=\frac{a}{\alpha+\beta-\gamma}\{\beta e^{-\gamma x}+(\alpha-\gamma)e^{-(\alpha+\beta)x}\},$$

where a is the amount of binoxide present in the solution at the commencement of the action, α the fraction of it which disappears in a unit of time by the action of the oxalic acid, β the fraction of it converted into the other oxide, and γ the fraction of this lower oxide which disappears in a unit of time.

In the following Tables some of the numbers obtained in the preceding experiments (pp. 206 & 210) are compared with those calculated from equations of this form. It will be seen that in general the three fractions upon which the whole rate of action depends increase as the sulphuric acid is increased, and that α increases more rapidly than γ; α being first less than γ, then equal to it, and finally greater.

The number and exactness of our experimental results are not, however, sufficient to make the calculation of the three constants in these equations more than approximate, and thus no such comparison can be made of the rates of change with different amounts of sulphuric acid as might serve to reveal how these quantities are related. In the first of the following Tables the residues of the two oxidizing substances at the time of each determination are given separately for two series; in the second Table several other series are compared with numbers similarly calculated according to the equations written over them.

TABLE XI.

Residues of oxidizing substance calculated from the equations

$$u=ae^{-(\alpha+\beta)x},\quad v=\frac{a\beta}{\alpha+\beta-\gamma}\{e^{-\gamma x}-e^{-(\alpha+\beta)x}\},\quad y=u+v,$$

where u and v are the residues of the primary and secondary oxide, and y is the total residue.

1. Case $\gamma>\alpha$ (Second set (p. 215) $n=1$).				2. Case $\alpha>\gamma$ (Second set (p. 215) $n=8$).			
x.	u.	v.	y.	x.	u.	v.	y.
0	37·4	0	37·4	1	11·6	11·0	22·6
2	21·0	13·8	34·8	1½	5·8	11·2	17·0
4	11·8	19·9	31·7	2	2·9	10·4	13·3
6	6·7	22·0	28·7	2½	1·5	9·0	10·5
8	3·7	22·0	25·7	3	0·7	7·8	8·5
10	2·1	20·8	22·9	3½	0·4	6·5	6·9
12	1·2	19·1	20·3	4	0·2	5·6	5·8
14	0·7	17·4	18·1	4½	0·1	4·6	4·7
18	0·4	13·8	14·2	5	0·0	3·9	3·9
22	0·2	11·0	11·2	5½	0·0	3·3	3·3
26	0·1	8·7	8·8				
30	0·1	6·7	6·8				
34	0·0	5·4	5·4				
40	0·0	3·7	3·7				
46	0·0	2·6	2·6				

TABLE XII.—Comparison of found and calculated results.

(The calculated numbers are derived from equations of the form $y=a_1e^{-\alpha_1x}+a_2e^{-\alpha_2x}$).

1. First set.

$n=10$. $y=28{\cdot}5({\cdot}82)^x+2{\cdot}7({\cdot}98)^x$.			$n=11$. $y=29({\cdot}785)^x+3{\cdot}1({\cdot}97)^x$.			$n=12$. $y=29{\cdot}4({\cdot}76)^x+3{\cdot}5({\cdot}96)^x$.		
x.	y.		x.	y.		x.	y.	
	Found.	Calculated.		Found.	Calculated.		Found.	Calculated.
½	25·85	25·9	1	20·8	20·8	1	20·0	20·1
1	21·55	21·4	1½	16·9	16·9	1½	16·05	15·9
1½	17·9	17·8	2	13·85	13·8	2	12·75	12·6
2	14·9	14·9	2½	11·4	11·3	2½	10·15	10·2
2½	12·55	12·5	3	9·4	9·4	3	8·35	8·3
3	10·45	10·4	3½	7·85	7·8	3½	6·75	6·8
3½	8·95	9·0	4	6·65	6·7	4	5·55	5·6
4	7·7	7·8	4½	5·6	5·6	4½	4·7	4·7
4½	6·65	6·6	5	4·7	4·8	5	4·05	4·1
5	5·7	5·8				5½	3·5	3·5
6	4·45	4·5				6	3·0	3·0
						9	1·85	1·9

TABLE XII. (continued).

2. Second set.

$n=1$. $y=42{\cdot}7(\cdot94)^x-5{\cdot}3(\cdot75)^x$.			$n=3$. $y=37{\cdot}9(\cdot873)^x$.			$n=4$. $y=32{\cdot}6(\cdot842)^x+5{\cdot}3(\cdot676)^x$.		
x.	y.		x.	y.		x.	y.	
	Found.	Calculated.		Found.	Calculated.		Found.	Calculated.
2	34·75	34·8	1	32·9	33·1	1	31·0	31·0
4	31·75	31·7	2	28·95	28·9	3	21·05	21·0
6	28·6	28·7	3	25·4	25·2	5	14·45	14·4
8	25·75	25·7	4	21·9	22·0	7	10·05	10·0
10	23·1	22·9	5	19·3	19·2	9	7·0	7·1
12	20·55	20·3	7	14·85	14·7	11	4·9	5·0
14	18·3	18·1	9	11·35	11·2	13	3·45	3·4
18	14·15	14·2	11	8·55	8·6	15	2·5	2·4
22	11·2	11·2	13	6·45	6·6	17	1·55	1·7
26	8·95	8·8	15	5·0	4·9			
30	6·7	6·8	17	3·85	3·8			
34	5·25	5·4	19	2·9	2·9			
40	3·9	3·7	23	1·6	1·7			
46	2·55	2·6						

$n=5$. $y=33{\cdot}7(\cdot794)^x+4{\cdot}2(\cdot501)^x$.			$n=8$. $y=25{\cdot}2(\cdot689)^x+20{\cdot}8(\cdot251)^x$.			$n=10$. $y=31{\cdot}4(\cdot417)^x+6{\cdot}4(\cdot75)^x$.		
x.	y.		x.	y.		x.	y.	
	Found.	Calculated.		Found.	Calculated.		Found.	Calculated.
1	29·05	28·9	1	22·5	22·6	1	18·05	17·9
2	22·4	22·3	$1\frac{1}{2}$	17·1	17·0	2	8·95	9·0
3	17·1	17·4	2	13·4	13·3	3	5·1	5·0
4	13·5	13·6	$2\frac{1}{2}$	10·5	10·5	4	3·1	3·0
6	8·5	8 6	3	8 5	8·5	5	1·9	1·9
7	6·7	6·7	$3\frac{1}{2}$	6·9	6·9			
8	5·5	5·3	4	5·8	5·8			
10	3·4	3·4	$4\frac{1}{2}$	4·8	4·7			
12	2·1	2·1	5	3·9	3·9			
14	1·6	1 3	$5\frac{1}{2}$	3·4	3·3			

The actual readings of the burette are given above instead of the amounts per cent., in order to show more clearly what is the practical limit of error in this mode of experimenting. The earlier series of numbers in the first set (Table VIII.) are omitted, because they are not sufficiently prolonged to be characteristic. Of the second set that corresponding to three proportions of sulphuric acid is perfectly geometric, while those on either side of it, corresponding respectively to one and to four proportions of acid, are not. It will be shown that this curious circumstance depends upon the existence of a particular relation between two of the three rates.

The foregoing experiments prove that the reaction here examined is of a complex character, and thus unsuited to the purpose with which we entered upon this investigation. The law that the amount of chemical change in a unit of time is proportional to that of each of the substances reacting, rather serves to explain these results than is established by them. Its truth, however, appears to be demonstrated in another and simpler case of chemical change which we have since examined, and therefore it may now be fairly applied to the elucidation of results which when first obtained were uninterpretable.

On this simpler case—the reaction occurring between hydriodic acid and peroxide of hydrogen—we have made numerous series of experiments, varying in succession each condition of the reaction. The results of this investigation, which is now nearly completed, may, we hope, form the subject of a second communication.

APPENDIX,

containing a Theoretical Discussion of some cases of Chemical Change.

By WILLIAM ESSON, *M.A., Fellow of Merton College, Oxford.*

THE most simple case of chemical change occurs in a system in which a single substance is undergoing change in presence of a constant quantity of other substances, and at a constant temperature. A practical constancy of the other substances is obtained by having them present in large excess; for any change produced in their amount by reason of the change of the single substance is infinitesimal in comparison with their original amount, and its effect on the system may therefore be neglected.

By a "system" is meant a unit of volume in which given quantities of substances are present; these quantities are called "elements of the system;" "a system in which a single substance is undergoing change," is a system in which the variation of the other substances does not affect the change of the single substance.

It has been ascertained by experiment that the residue y of the substance undergoing change in a system of this kind, is connected with the time x during which the change has been proceeding, by the following equation,

$$y=ae^{-\alpha x}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

a being the quantity of the substance in the system at the commencement of the change, and α a constant, the meaning of which may be thus determined; differentiating (1) and eliminating x, we have

$$\frac{dy}{dx}=-\alpha y. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Now $-\frac{dy}{dx}$ is the amount of substance which disappears in a unit of time at the time x, when y is the quantity of substance present in the system, and the equation (2) expresses the law that "the amount of change in a unit of time is directly proportional to the quantity of substance;" following the analogy of the motion of a material particle, we may call $\frac{dy}{dx}$ the rate or velocity of chemical change, and the law may be thus stated:— "The velocity of chemical change is directly proportional to the quantity of substance undergoing change."

The constant α expresses the fraction of the substance which is changed in a unit of time; this fraction depends upon the other elements of the system, and upon its physical conditions, such as temperature, density, &c. By varying each of these conditions in succession, it is possible to determine α as a function of them, and to predict the progress of the chemical change of a single substance, from its commencement to its completion, under any assignable conditions.

This simple case of chemical change is of comparatively rare occurrence. Two instances of it are recorded in the preceding pages (pp. 209 & 210, $n=3$). It is necessary therefore to investigate the modifications which the general law undergoes in the case of complex reactions.

Let us first take the case in which the chemical change consists of the reaction of two substances, neither of which is present in the system in great excess. In the discussion of this case we shall assume the general truth of the law of variation of the rate of chemical action, which has been derived from experiments in which the constancy of all the elements but one has been secured by taking them in excess. In fact we shall assume that the truth of the law depends only upon the constancy of the elements, and not upon their excess. Since, then, the velocity of change of each substance is proportional to its quantity when the quantity of the other is constant, it follows that the velocity of change is proportional to the product of the quantities when both vary. Let a, b be the number of equivalents of the substances present in the system at the commencement of the reaction, z the number of equivalents of each which has disappeared during a time x, then $a-z$, $b-z$ are the number of equivalents remaining at the end of that time; hence

$$\frac{dz}{dx}=n(a-z)(b-z), \quad \dots\dots \quad (3)$$

the solution of which is

$$\log\left(1-\frac{z}{a}\right)-\log\left(1-\frac{z}{b}\right)=n(a-b)x, \quad \dots\dots \quad (4)$$

an equation for determining the amount of chemical change, in this case, after the lapse of a given time.

When the substances are originally present in equivalent quantities, $a=b$, and (3) becomes

$$\frac{dz}{dx}=n(a-z)^2, \quad \dots\dots \quad (5)$$

the solution of which is

$$z=a\frac{nax}{nax+1}. \quad \dots\dots \quad (6)$$

The equation connecting the residue y with the time is in this case

$$y=\frac{a}{nax+1}; \quad \dots\dots \quad (7)$$

and if at the commencement of the reaction the substances had been present in infinitely large quantities,

$$y=\frac{1}{nx}. \quad \ldots \ldots \ldots \ldots \quad (8)$$

The curve (6), which expresses the reaction of two substances originally present in equivalent quantities, is a rectangular hyperbola, and when the original quantities are infinite, the residue varies inversely as the time. This result has been already referred to at pages 202 & 203, where experimental evidence of the relation has been adduced. That evidence is, however, somewhat impaired by the fact that the numbers which express the percentage of chemical change during the first four or five minutes fail to satisfy this relation; but it may be shown that this failure is probably due to the gradual formation of one of the substances which take part in the reaction.

Let us suppose that at the commencement of the reaction there are present a equivalents of a substance A, which during the course of the reaction is gradually changed into an equivalent quantity of a substance B, and that B reacts with a substance C of which a equivalents are originally present; also let u be the number of equivalents of A which remain after an interval x, and v the number of equivalents of B which remain after the same interval; then, since the velocity of diminution of u is proportional to its quantity, and the velocity of diminution of v proportional to the product of its quantity into the quantity of c, and the velocity of increase of v equal to the velocity of diminution of u, we have the following equations,

$$\frac{du}{dx}=-\beta u, \quad \ldots \ldots \ldots \ldots \quad (9)$$

$$\frac{dv}{dx}=-\alpha v(u+v)+\beta u. \quad \ldots \ldots \ldots \ldots \quad (10)$$

The solution of (9) is

$$u=ae^{-\beta x}; \quad \ldots \ldots \ldots \ldots \quad (11)$$

so that if the residue of u could be measured separately from that of v, the rate of change of u into v could be determined, but in the actual experiments u and v are determined together, and the relation between the total residue $y(=u+v)$ and the duration of the reaction x is consequently very complex.

Adding (9) and (10), we have,

$$\frac{dy}{dx}+\alpha vy=0; \quad \ldots \ldots \ldots \ldots \quad (12)$$

substituting for dx from (9), and for v its value $y-u$, we obtain the equation

$$\frac{dy}{y^2du}+\frac{\alpha}{\beta y}-\frac{\alpha}{\beta u}=0, \quad \ldots \ldots \ldots \ldots \quad (13)$$

the solution of which is

$$\frac{\alpha}{\beta}e^{\frac{\alpha}{\beta}u}\left\{c-\log u+\frac{\alpha}{\beta}u-\frac{1}{1.2^2}\left(\frac{\alpha}{\beta}u\right)^2+\ldots\right\}y=1. \quad \ldots \ldots \ldots \quad (14)$$

If we replace for u its value $ae^{-\beta x}$, we obtain an equation connecting the residue y with the time x. In the experiments to which this hypothesis is applicable (p. 204), the value of u becomes inappreciable after the action has gone on for about six minutes, so that after that time the course of the action satisfies the relation,

$$\frac{\alpha}{\beta}(c-\log a+\beta x)y=1, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

or

$$(c'+x)y=\frac{1}{\alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

An equation of the form (16) is satisfied by all the numbers recorded in page 203 after $x=6$, the values of c' and $\frac{1}{\alpha}$ being 0·1 and 157. Assuming for β the value ·69, we obtain for c the value 4·68. Substituting these values in (14), we obtain the following series of numbers for the values of y between 2 and 6. The earlier numbers are omitted because the experimental values of y exhibit an irregularity, which is probably due to errors of experiment which occur in short intervals of time less than one minute. The numbers after $x=6$, obtained from the equation $(x+{\cdot}1)y=157$, are given at p. 203.

	y.	
x.	Found.	Calculated.
2	51·9	51·6
3	42·4	42·9
4	35·4	35·4
5	29·8	29·7

Considering the experimental evidence, and the fair agreement of the numbers in the preceding Table, there seems to be sufficient ground for believing that in this case the chemical change consists of the gradual formation of a substance which at the same time slowly disappears by reason of its reaction with a proportional quantity of another substance.

The rate of formation of the substance, and the fraction β which is formed in a unit of time, depend upon the conditions of the system, just in the same way as its rate of decomposition depends upon these conditions. It would, however, be a hopeless task to attempt to discover the relation between α, β and the conditions of the system, when we have to deal with a series of complex equations like (14). This complexity explains the failure to discover any simple relation in the case of the variation of sulphuric acid referred to at p. 195.

The next case to be considered is that of a system in which there are two substances undergoing change in presence of a large excess of the other elements of the system. If both substances are present in the system from the commencement of the change and are independent of each other, the velocity of diminution of each is proportional to its quantity, and their residues accord with the simple law $y=ae^{-\alpha x}$; and if both these residues are measured together, the equation of the reaction is

$$y=a_1e^{-\alpha_1 x}+a_2e^{-\alpha_2 x}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

a_1, a_2 being the quantities of the substances originally introduced into the system, and α_1, α_2 the fractions of them which disappear in a unit of time.

If, however, the substances are not independent, but are such that one of them is gradually formed from the other, we have a different system of equations to represent the reaction.

Let u, v be the residues of the substances after an interval x, $y(=u+v)$ being the total residue actually measured at that time. Let the initial values of u and v be $u=a$, $v=0$; let αu be the rate of diminution of u due to its reaction with one of the other elements of the system, and βu its rate of diminution due to its reaction with another of the elements of the system, by means of which v is formed, and let γv be the rate of diminution of v, then

$$\frac{du}{dx}=-(\alpha+\beta)u, \quad \ldots\ldots \quad (18)$$

$$\frac{dv}{dx}=\beta u-\gamma v, \quad \ldots\ldots \quad (19)$$

whence

$$u=ae^{-(\alpha+\beta)x}, \quad \ldots\ldots \quad (20)$$

$$v=\frac{a\beta}{\alpha+\beta-\gamma}\{e^{-\gamma x}-e^{-(\alpha+\beta)x}\}, \quad \ldots\ldots \quad (21)$$

$$y=\frac{a}{\alpha+\beta-\gamma}\{\beta e^{-\gamma x}+(\alpha-\gamma)e^{-(\alpha+\beta)x}\}. \quad \ldots\ldots \quad (22)$$

There are several particular cases of these equations which require to be considered separately.

(1) $\beta=0$. Fraction of v formed$=0$.

In this case the system of equations reduce to

$$u=ae^{-\alpha x},$$

$$v=0,$$

$$y=ae^{-\alpha x}.$$

The experimental case corresponding to this is that recorded on page 209.

(2) $\gamma>\alpha$. Fraction of v decomposed in a unit of time, greater than the fraction of u decomposed in a unit of time.

In this case the last equation of the system is of the form

$$y=a_1e^{-\alpha_1x}-a_2e^{-\alpha_2x}.$$

The experimental case corresponding to this is that recorded on pages 210, 215, $n=1$.

(3) $\gamma=\alpha$. The fraction of v decomposed in a unit of time equal to the fraction of u decomposed in a unit of time.

In this case the last equation of the system reduces to the form

$$y=ae^{-\alpha x}.$$

The experimental case corresponding to this is recorded on pages 210, 215, $n=3$.

(4) $\gamma<\alpha$. The fraction of v decomposed in a unit of time greater than the fraction of u decomposed in a unit of time.

In this case the last equation of the system is of the form

$$y=a_1e^{-\alpha_1x}+a_2e^{-\alpha_2x}.$$

The experimental cases corresponding to this are recorded on pages 210, 215, $n=4$, 6, 8, 10.

It is thus possible to have all these four cases in succession in a set of experiments in which only one condition is progressively varied, provided that the variation of γ and α is such that γ is at first greater than α, but increases in a less ratio than α. Several attempts have been made to calculate equations of the form $y=a_1e^{-\alpha_1x}\pm a_2e^{-\alpha_2x}$ which should give the experimental numbers within the errors of experiment, and at the same time yield values of the fractions α, β, γ from which the law of their variation with a variable quantity of sulphuric acid could be discovered. Some of these equations are recorded on page 214. The number and exactness of the experimental results are, however, not sufficient to enable us to extract from the complicated equation

$$y=\frac{a}{\alpha+\beta-\gamma}\{\beta e^{-\gamma x}+(\alpha-\gamma)e^{-(\alpha+\beta)x}\}$$

trustworthy values of α, β, γ, and this inexactness precludes the possibility of investigating the law of their variation when the conditions of the experiment are varied. What we can state with certainty is, that the numbers are all satisfied by equations of the forms

$$y=a_1e^{-\alpha_1x}-a_2e^{-\alpha_2x},$$

$$y=ae^{-\alpha x},$$

$$y=a_1e^{-\alpha_1x}+a_2e^{-\alpha_2x},$$

and that successive sets of numbers, obtained by varying one condition progressively, are satisfied by these successive forms of equations. These forms, and the order of their succession, are accounted for by a hypothesis for which there is considerable experimental evidence, and it is thus highly probable that the results arrived at in the above discussion give a true account of the progress of the reaction.

The law of variation of α, β, γ with the conditions of the system will probably be detected when the case in which β, γ both vanish for all conditions of the system, has been fully discussed.

A complete investigation of this case is reserved for a future communication.

XI. *On the Chameleon's Retina; a further Contribution to the Minute Anatomy of the Retina of Reptiles. By* J. W. Hulke, *F.R.C.S., Assistant Surgeon to the Middlesex and Royal London Ophthalmic Hospitals. Communicated by* William Bowman, *F.R.S.*

Received June 1,—Read June 15, 1865.

The chameleon's retina is remarkable in two respects: 1st, it has a yellow spot and fovea centralis*; and 2ndly, the fibres which connect the cones with the inner layers cross the connective-tissue radial fibres instead of running parallel to them†.

The yellow spot lies in the centre of the retina, at the posterior pole of the globe. The fovea is a deep circular pit. Its bottom (*i. e.* centre) appears as a dark-brown dot, encircled by a lighter brown ring corresponding to the sides of the pit, and this in turn is surrounded by a colourless zone, the outer edge of which passes gradually into the colour of the surrounding parts (Plate XIX. fig. 1).

A flat subconical pecten, rising $\frac{1}{33}''$ above the inner surface of the retina, marks the entrance of the optic nerve, $1'''$, at the temporal side of the fovea. The nerve pierces the sclerotic very obliquely, and its bundles, escaping from the base of the pecten in the level of the ganglionic layer of the retina, are distributed on the inner retinal surface in such a manner that those only which belong to the fovea run directly towards this from the pecten, while all other fibres for parts on the nasal side of the pecten arch above and below the fovea in increasingly open curves.

Minute Structure.

1. *Bacillary Layer.*—Cones only occur in this layer (figs. 2 & 3). They consist of an inner and an outer segment, separated by a bright transverse line. The outer segment is a very slender, strongly-refracting shaft; it tapers slightly towards its outer end; its length increases from the periphery to the centre of the retina, but is always much less than that of the inner segment. It is completely buried in the choroid, which also sheaths the outer part of the inner segment. This latter segment, although much larger than the outer, is inconspicuous in fresh specimens in consequence of its low refraction. At the centre of the retina its length is very considerable, while its breadth scarcely exceeds that of the outer segment; these proportions give the cones in this part the appearance of tall slender pillars; but at the periphery the inner segment is stout, and the cones resemble tall flasks. In chromic acid preparations the outer part of the flask-shaped cone-body is finely granulated, while the inner is more homogeneous, and often exhibits

---

* Knox, Mem. Wern. Soc. vol. v. p. 2, and Edinb. Phil. Journal, Oct. 1823, p. 358.

† Müller, H., Würzb. Naturwiss. Zeitschr. 1862, Bd. III. Heft 1. S. 20.

an oval or stellate vacuole, regarded by MÜLLER as a nucleus, and which is not to be mistaken for an outer granule.

The difference between these extreme forms of cones in the centre and in the periphery of the retina is so great, that, judging from their shape alone, they might not be unreasonably regarded as different elements; but a regularly progressive change from one to the other shape in passing from the centre of the retina outwards, and the constant presence of a bright pale yellow or colourless bead in the outer end of their inner segment, establish their identity and conic nature. As their stoutness decreases from the periphery to the centre of the retina, each successive unit of surface in this direction contains more cones; and since each cone has its outer granule associated with it, the numerical increase of the cones is attended with a corresponding increase in the number of the outer granules. The inner ends of the cones pass through apertures in the membrana limitans externa, which in its structure and relations resembles that of other reptiles.

2. *The Outer Granule-Layer.*—The so-called "granules" are large, round, and roundly-oval nuclei, about $\frac{1}{6000}''$ in diameter. In the periphery of the retina, where the cones are stout, they lie in a single tier, one in the inner end of each cone, in or slightly inside the plane of the membrana limitans externa; while towards the fovea, where the slenderness of the cones does not allow them to enclose their outer granule, the granules form a separate layer, and each is connected with its cone by an intermediate fibre, continuous with the inner end of the latter. These fibres, for which I would suggest the term "primitive cone-fibres," are identical with those I have described as coming off from the inner end of the rods and cones in other reptiles, but their course and arrangement in the chameleon are peculiar.

3. *Cone-fibre Plexus.*—In the periphery of the retina, where the cones enclose their outer granule, the primitive fibres, on leaving the inner end of the cones, curve vertically inwards and combine in bundles, which run for a considerable distance horizontally towards the periphery, and then again bend vertically inwards among the inner granules. In the central region, where the cones are slender and numerous and the outer granules lie in several tiers, the primitive cone-fibres first bend inwards from the cones, next take up their outer granule, and then, at the inner surface of the outer granule-layer, combine in bundles which unite in a plexiform manner to form a layer that attains a remarkable thickness at the border of the fovea centralis. The inclination of the bundles, and their combination in the plexus, is such that the outer bundles are gradually brought to the inner surface of the plexus. Here they are again resolved into primitive fibres that curve inwards through the intergranule-layer to the inner granules (fig. 4*b*). H. MÜLLER relates that in his hardened preparations he could not determine whether the finer fibres were merely stuck together in the bundles of the plexus, or whether divisions took place; my belief is that they cohere very closely in the bundles of the plexus, but that they never fuse or split. Lying between the outer and the inner granules, this plexus was called by MÜLLER the intergranule-layer,

a name which I give to a thin band of connective tissue that bounds the outer surface of the inner granule-layer, and which corresponds to the intergranule-layer of other reptiles (fig. 5 *i*).

A second set of fibres, corresponding to those which in the Turtle's retina I named the outer radial fibres, crosses the cone-fibre plexus nearly perpendicularly. These vertical radial fibres are most developed where the plexus is thickest (fig. 5). Near the fovea they are very conspicuous, particularly in carmine preparations, in which they are almost colourless, while the bundles of cone-fibres have a deep red tint. In sections parallel to the cone-fibre bundles we see the vertical radial fibres traversing the meshes of the plexus; while in sections across the bundles, the cut ends of these are packed in long vertical spaces between the radial fibres, which last appear as stout vertical pillars that divide at acute angles, and becoming fine and numerous, end at the inner surface of the membrana limitans externa. Near the inner surface of the plexus, the stout pillar-like fibres also repeatedly divide, the resulting fibrillæ spread in a fan-like manner, and interweaving with others from neighbouring trunks, form the thin band which I call the intergranule-layer. Through this layer the primitive cone-fibres pass to the inner granules.

The above description of the outer vertical radial fibres and intergranule-layer applies particularly to the central region of the retina; in the periphery, where the retina is thin, a distinct intergranule-layer is not present, and the *outer* vertical radial fibres are replaced by vertical radial fibres which pass from the inner to the outer limiting membrane.

4. *The Layer of Inner Granules.*—This layer throughout the retina is thicker than that of the outer granules. It reaches its greatest development around the fovea centralis, and diminishes towards the periphery in a more gradual manner than the outer granule-layer. Several distinct forms of *cells* and *nuclei*, and two sets of fibres, a *vertical* and an *oblique*, are distinguishable in it. Near the outer surface of the layer, in the central region in close relation to the vertical set of fibres just mentioned, we find small oat-shaped nuclei which carmine scarcely stains. Besides these, other minute nuclei, bright, angular, and also scarcely tinted by carmine, are scattered throughout the layer, apparently in relation with the vertical fibres and interstitial connective tissue.

Of the *cells*, some are of a round and roundly oval form, from $\frac{1}{9000}''$ to $\frac{1}{4500}''$ in diameter. Carmine stains them deeply, and many contain a minute nucleus (figs. 6 & 7). In rather thick sections, in which the relations of the elementary parts are less disturbed, these cells are often seen disposed in linear series parallel to the oblique fibrillation to be presently described. Where the layer is broad, they are most numerous in its middle third. There are other cells which are much larger and of an irregular figure (figs. 8, 9, & 10). These have a faint single outline, a pale, finely granulated texture, and contain a large, round, sharply-defined nucleus which nearly fills them, averaging $\frac{1}{3000}''$. They occur principally near the inner surface of the layer, and are less numerous than the smaller cells. I have frequently seen a broad, flat, pale process pass inwards from these large multiangular cells into the granular layer, and here break up into very fine parallel fibres, which I have traced nearly to the ganglionic layer, and believe to be continuous with processes from the cells of this layer. On the outer side the cells are connected with the oblique fibres.

These fibres (figs. 7, 8, 9, 10, & 11) are directed obliquely from the outer to the inner surface of the layer, and from the centre towards the periphery of the retina. Their obliquity diminishes towards the inner surface of the layer, where many of them are nearly horizontal. In the outer part of the layer they are very fine and numerous, in the middle they are thicker and fewer, while in the inner third their numbers still further decrease, and they become stouter and flatter. This results from the union of the primitive fibres in bundles, which have an open plexiform arrangement. In the thin periphery of the retina the whole course of the fibres is more horizontal.

The following are the relations of the oblique fibres and the other tissues. The finest fibres in the outer part of the layer are continuous through the intergranule-layer with the primitive fibres of the cone-fibre plexus, as I have already mentioned in describing this; they also take up the smaller round and roundly oval inner granules. Combining as they pass through the layer, becoming stouter and more horizontal, they join the large ganglion-cell-like cells which lie near the inner surface of the layer, and the pale band-like fibres which these cells send into the granular layer may be regarded as their further continuations.

5. *The Granular Layer.*—Around the fovea the thickness of this layer nearly equals that of the inner granules; from this point it very gradually decreases towards the periphery of the retina. Its minute structure is a close and intricate web of exceedingly fine soft filaments. It is marked by horizontal parallel bands, which appear to result from a longitudinal disposition of the filaments.

Two sets of vertical fibres are distinguishable in it. The first are connective fibres passing outwards from the membrana limitans interna; they are finer near the centre than at the periphery of the retina. They divide at acute angles, and give off fine lateral branches which are lost in the proper tissue of the layer.

The second set consists of the fibres which pass inwards from the large multipolar inner granules (which I look upon as ganglion-cells), and of those passing outwards from the cells of the ganglionic layer. I have already said that I believe these fibres are continuous. I have occasionally seen large ganglionic cells in vacuoles in the middle of this layer, at a distance from the inner granules and ganglionic layer.

6. *The Ganglionic Layer.*—The cells of this layer are distinctly multipolar (fig. 12). They have a faint single outline, a soft, finely granulated texture, and a very conspicuous large circular nucleus. On the one side they send off the fibres mentioned in the account of the granular layer, while on the other they send fibres, which cannot be distinguished from nerve-fibres, to the plexiform expansion of the optic nerve. Around the fovea they lie four or five deep; their numbers increase for about $\frac{1}{2}'''$ from this in a peripheral direction, and then decrease.

7. *Optic Nerve-layer.*—The general appearances of the optic nerve have been already described; its finer distribution does not exhibit any special characters. The bundles are disposed in a plexus, the meshes of which transmit the connective radial fibres.

The plexus is separated from the membrana limitans interna by a narrow band, which has a finely granular and striated texture. Its minute structure agrees with that of the granular layer. This band is bounded by the membrana limitans interna, from the inner surface of which the connective radial fibres arise by fine converging roots; their course has been given in the descriptions of the different layers.

Fovea Centralis.

Owing to the great thickness of the retina immediately around it (fig. 13), the fovea is encircled by a raised margin, from which the surface rapidly declines centrally to the bottom of the fovea, while it slopes gently towards the periphery of the retina. Opposite its margin the optic nerve, granular, inner granule, layers, cone-fibre plexus, and the *inner limit* of the outer granule-layer, begin to bend outwards, and becoming gradually thinner, they converge to the bottom of the fovea, where they cease, the cones (with their fibres diverging on all sides towards the outer granule-layer) alone, covered by a thin fibro-granular band, existing at this spot.

Reviewing the layers at the fovea in order, from the inner surface of retina outwards, we find the *optic nerve-fibres* in decreasing number from the margin to the bottom of the fovea.

The *ganglion-cells* around the bottom lie in a single and interrupted series, which, midway *towards* the margin, becomes continuous, and double or treble, while *at* the margin the cells lie four or five deep. The greatest development of the ganglionic layer is not, however, here, but about $\frac{1}{2}'''$ from the centre of the fovea.

The *granular layer* blends in the bottom of the fovea with the granular band, which in other parts lies between the optic nerve-layer and the membrana limitans interna. This band in the fovea exhibits a very distinct vertical striation.

The *inner granule-layer*, in sloping towards the bottom of the fovea, closely approaches the outer granule-layer, as the cone-fibre plexus which lies between them becomes thinner. It attains its maximum development slightly nearer the fovea than that of the ganglionic layer.

The *cone-fibre plexus* commences near the bottom of the fovea, in the angle between the inner and outer granules, and steadily increases in breadth till it reaches its maximum development, slightly nearer the fovea than that of the inner granules.

The *outer granule-layer*, also commencing near the bottom, swells very rapidly, and opposite the margin of the fovea acquires a remarkable thickness. From this point it slowly declines for about $\frac{3}{4}'''$ from the fovea, and then becomes abruptly thin. Its extraordinary enlargement immediately around the fovea is due to the presence here, not only of the outer granules which belong to the cones lying immediately at its outer surface, but also of those outer granules that belong to the cones which lie at the centre of the fovea. Besides which the great proportional number of cones in the fovea is attended with a corresponding increase in the number of the outer granules.

Conal Layer.—The cones become thinner, longer, and more numerous from the periphery to the centre of the retina, *i. e.* of the fovea. At the centre of the fovea they reach the extraordinary length of $\frac{1}{360}''$. In fresh specimens the characteristic bead in the outer end of the inner segment of the cones here was conspicuous, though very minute.

A careful study of many sections has convinced me that the cones stand vertically on the choroid; the primitive fibres proceeding from them to the outer granules do, however, incline on all sides from the centre of the fovea; and the bundles of the cone-fibre plexus, as also the oblique fibres in the inner granule-layer, are similarly deflected.

Enumerated briefly, the peculiarities of the fovea consist in the attenuation of the optic nerve, ganglionic, granular layers, and cone-fibre plexus, from its margin towards its centre; in the absence of these layers *at* the centre; in the great slenderness and length of the cones; in the deflection of the primitive cone-fibres and of their continuations in the outer and inner granule-layers from the centre towards the periphery; and in the maximum development of all the layers, excepting the bacillary, at successively increasing distances from the centre of the fovea in their order of superposition from the outer to the inner surface of the retina.

EXPLANATION OF PLATE.

PLATE XIX.

Fig. 1. An enlarged view of the Fovea centralis in the fresh retina.

Fig. 2. Cones from the Fovea: *a*, the outer; *b*, the inner segment.

Fig. 3. Cones from the periphery of the retina: *a*, the outer segment; *b*, the inner segment containing, *d*, an outer granule, and produced inwards as a primitive fibre through the membrana limitans externa; *c*, intended to mark this latter (the horizontal line), has been placed too high by the artist.

Fig. 4. A vertical section near the Fovea parallel to *a*, the bundles of the cone-fibre plexus; *b*, primitive fibres passing from these bundles through *d*, a granular stratum, into the inner granule-layer; *c*, the outer vertically-radial connective-tissue fibres.

Fig. 5. A vertical section through the outer layers near the Fovea. Only the connective-tissue frame is represented: 1, the bacillary layer; 2, the outer granule-layer; 2′, the cone-fibre plexus; 3, a granular stratum representing the intergranule-layer; *c*, the membrana limitans externa; *f*, the trunks of the outer vertically-radial connective-tissue fibres; *g*, their outer ends, branching and terminating in the membrana limitans externa (the artist has drawn these too thick); *h*, the branching inner ends of the fibres forming the intergranule-layer and terminating in *i*, a thin band bounding the outer surface of the inner granule-layer; *k*, the vertically-radial connective-tissue fibres in the inner granule-layer.

Figs. 6 & 7. Oblique fibres in the inner granule-layer arranged in a plexiform manner, with smaller inner granules.

Fig. 8. A vertical section through the inner granule-layer, near its inner surface: *a*, larger inner granules (= ganglion-cells?); *b*, fibres passing from them into the granular layer.

Fig. 9. Two larger inner granules, from the same situation: *a*, *b* indicate the same parts as in the preceding figure; *c*, a vertically-radial connective-tissue fibre.

Fig. 10. A vertical section near the inner surface of the inner granule-layer: *a*, smaller; *b*, larger inner granules; *c*, a vertically-radial connective-tissue fibre; *d*, stout band-like (nervous) fibres resulting from the union of the finer oblique fibres, and directed radially from the centre towards the periphery of the retina and from the outer towards the inner surface.

Fig. 11. Two larger (ganglion-cell like) inner granules.

Fig. 12. Ganglion-cells and optic nerve-fibres.

Fig. 13. A vertical section through the Fovea, ×20: 1, bacillary layer (at its outer surface the choroid); owing to a slight artificial folding of this layer the cones are represented as decreasing slightly in length from the edge to the centre of the fovea instead of increasing as they actually do; 2, the outer granule-layer followed by the cone-fibre plexus; 3, the intergranule-layer; 4, the inner granule-layer; 5, the granular layer; 6, the ganglionic and optic-nerve layers.

XII. *On the Expansion by Heat of Water and Mercury.* *By* A. MATTHIESSEN, *F.R.S.*

Received December 7,—Read December 21, 1865.

THE fact pointed out in my report "On the Chemical Nature of Alloys"[*], that their physical properties may in this respect be divided into two classes, namely (1) those which do not indicate their chemical nature, and (2) those which do indicate their chemical nature, has led me to investigate the property of expansion by heat, so as to find the law which regulates the expansion of alloys, as well as to determine to which of the above classes this property belongs.

To do this, it was first necessary to determine the coefficients of expansion of the metals to be employed in making the alloys; and in carrying out this research, it had to be borne in mind that bars of a sufficient length to determine the linear coefficients of expansion with accuracy would require very large quantities of the pure metals to make the alloys, in fact such quantities as it would be impracticable to prepare. A method had therefore to be devised by which the expansion of small quantities of the metals and their alloys could be determined, and at once one suggested itself, namely, that of weighing the metal or alloy in water of different temperatures. This method has been already employed for the determination of the coefficient of expansion of water by HÅLLSTRÖM and HAGEN.

To check the method (basing the calculations on KOPP'S coefficients of expansion for water), the expansion of mercury was determined. The coefficient deduced did not, however, agree with REGNAULT'S, as was expected, but, on the contrary, differed considerably; showing either an error in the method employed, or that either KOPP'S or REGNAULT'S coefficients are faulty. After carefully considering the method employed and obtaining always the same results, it then became necessary to redetermine the coefficients of expansion of water and mercury; and these redeterminations form the subject of this memoir, which will be divided into four parts:—

1. On the determination of the coefficient of linear expansion by heat of certain glass rods.
2. On the method employed for the determination of the coefficients of cubical expansion by heat of water and mercury.
3. On the redetermination of the coefficients of expansion by heat of water.
4. On the redetermination of the coefficient of expansion by heat of mercury.

---

[*] British Association Report, 1864.

I. *On the Determination of the Coefficient of Linear Expansion by Heat of certain Glass Rods.*

I am indebted to Mr. F. OSLER for kindly interesting himself in the subject, and having had made at his manufactory two glass rods especially for these experiments. From the ends of these rods pieces were cut, ground, and polished, to be used for weighing in water at different temperatures. The approximate mixture from which the rods were made was 3 parts sand, 2 lead, and 1 alkali.

The disposition of the apparatus used for the determination of the increment in length may be seen from fig. 1 (Plate XX.), which needs some explanation.

In the long zinc trough A (fig. 1) the rod was placed, the ends of it first passing through holes in the ends of the trough; into these openings were soldered pieces of zinc tubing (fig. 2, *a*, *a*) of about 50 millimetres long, so as to serve both as a rest for the rod passing through them, and as a means of making the trough water-tight. As the greater part of the zinc tubing projected inwards, it was easy to draw a piece of vulcanized rubber tubing over its end, and on passing the rod through this the trough became water-tight. The few millimetres of the zinc tube projecting outwards served to keep the ends of the glass rod (about 5–10 millims.), if not quite at the same temperature of the bath, at all events very near it. Three other rests were placed in the trough to support the rod (fig. 2, *b*, *b*, *b*). The length, width, and height of the trough were 1800, 180, 150 millimetres (measured inside). The long sides and top were made double. Through an opening in the cover the thermometer T is fixed, the bulb reaching in the water the level of the rod; a smaller one (T_1) is placed near the larger one, so as to give the mean temperature of the column of the mercury not immersed in the water; that is, its bulb is placed near the middle of the exposed column.

To give the necessary firmness to the apparatus, and to cause the expansion of the glass to be indicated in only one direction, the following arrangement was made. A hole was made in the wall so as to take the end *e* of tube B (fig. 1). Fig. 3 shows the construction of this part of the apparatus. It consists of a stout glass tube fitted into zinc caps, the ends of the tube touching the ends of the cap, so that when water enters at *d*, it is forced to flow to the end of the zinc cap to enter the tube, and to make its exit in the same manner at the other end. The zinc is connected with the glass by rubber tubing; the tube B, the end of which is cemented in the wall and supported by two bricks, to which the tube is also cemented, thereby forming a solid resistance for the one end of the rod to rest against. The communication between the other end of the rod and the measuring-apparatus is similarly constructed (fig. 4); the length of the fixed glass tube B being 300, and of the moveable one 350 millimetres. To steady the latter as much as possible, the tube passed through a larger one cemented to the brick, as shown in fig. 4. This allows the tube to move backward and forward with ease without altering otherwise its position. It was kept pressing on the end of the rod by the spring *i* (ordinary bell spring), a weight (*h*) hanging below it to serve to counteract the upward pulling of the spring. Similar springs (k, k, k, k) were fixed to the glass rod in the trough, to keep it pressed against the end of the fixed glass tube.

The whole of the apparatus stood on a brick floor, and so solid was the foundation, that accurate measurements could be made even when persons were moving about on it.

The measuring-apparatus* (D, fig. 1) was a micrometer-screw, a piece of brass being fixed to the end of it, through which passed a moveable circular piece of the same alloy faced with agate. On turning the screw, this piece of brass, as soon as it touched the zinc cap, pressed against the short arm of the lever (l), and thus indicated the point of contact. To obtain accurate readings, the screw was turned until the bent end of the long arm of the lever covered the line on the table beneath it; and to avoid parallax, the point was observed through the tube E, which has a very fine opening at the top and a magnifying glass at the bottom.

With this arrangement readings can be made with little practice (of course avoiding the back-lash of the screw), with great accuracy, in fact, easily to 0·001 millimetre.

The length-value of a turn of the micrometer-screw was found by measuring wires of known diameter. These were measured some years since in Heidelberg, in KIRCHHOFF'S laboratory, with a calibrated micrometer-screw under a microscope. I thought, however, the screw might have altered by constant use, as it had served to measure all the wires used for the electrical conducting-power experiments made in conjunction with other gentlemen. On applying to Mr. B. STEWART, he kindly placed at my disposal, at Kew, their normal measuring-screw, and on redetermining the length-value of a turn of the screw, it was found equal to 0·185 millimetre, agreeing almost absolutely with the former value, namely 0·184 millimetre. The mean of these two values was used, namely 0·1845 millimetre. The milled head was divided into 200 parts, so that each division represents about 0·001 millimetre. A small correction had to be made for the movement of the lever, as it moves bodily with the screw. The relative lengths of the arms of the lever were about as 250 : 1, so that when the screw moved backwards to allow the rod to expand, the error caused by this in the reading will be about 0·005 millimetre, for the expansion of the rod is equal to 1·3 millimetre; in other words, to bring the point of the lever to cover the line at the high temperatures, the screw would be turned too much, or the expansion would be found too small. By direct determination this correction amounts, for six turns of the screw, to 0·005 millimetre.

On carefully calibrating the screw, a part of it (consisting of eight turns) was found where the length-value of the threads was almost absolutely the same. This portion of the screw was therefore used for the experiments. The thermometers employed were correct, having been compared with a Kew Standard thermometer. Their zero-points were redetermined from time to time. The correction for the column of mercury not immersed in the water, made by using KOPP'S formula,

$$\text{correction} = N(T - t) \times 0{\cdot}0001545,$$

---

* This apparatus was made by Mr. BECKER for the accurate measurement of the diameters of wires.

where N is equal to the number of degrees exposed, T the uncorrected temperature of the water, and t the temperature of the thermometer the bulb of which is placed in contact with the stem of the other thermometer halfway between the top of the mercury column and the middle of the cork. The number given is the apparent expansion of mercury in glass.

Having thus described the different parts of the apparatus, I will proceed to state the manner of making the determinations. The different parts having been placed together, the trough was filled with water by connecting the tap F with the water-tap; and when full the water was still allowed to enter, escaping through a waste-pipe at the top of the other end of the trough. After the water had flowed through the trough for about half an hour, it was turned off at F and connected with *d*, flowing through B, and thence passing through the rubber tubing from *c* to *f*. At *f* it enters the tube C, and escapes at *g* into a waste-pipe. The temperatures of the thermometers having been read off, and the position of the screw noted when touching the end of the tube C, the eighteen Bunsen burners were lighted, the screw at the same time being turned so as to allow for the expansion of the rod. When the water boiled the temperatures were read off, and the new position of the screw noted on touching the end of C. It was found necessary to continue boiling the water for about a quarter of an hour before constant readings could be obtained. To take the readings again at low temperatures, the water-tap was connected with F, and the water allowed to flow through the trough till that flowing from the waste-pipe had the same temperature as the water from the tap, when the connexion was again made with *d*. To obtain this temperature, it took from three to four hours. It may here be mentioned that screens were placed between the ends of the trough and the tubes B and C, to prevent their being heated by radiation from the trough whilst making the observations at high temperatures. A thermometer placed near the screw of the measuring-apparatus showed no change of temperature during the time of the experiment, the room in which the experiments were made being a very large one.

Only such observations were deemed reliable as gave concordant results on heating and cooling the rod, the slightest movement in any part of the apparatus causing large differences in these values. No good results were obtained at first, but after some practice the values found agreed well together. These are given in Table I.

Nos. 1, 2, & 3 are the observations made with Rod I., with only two springs in the trough.

Nos. 4 & 5, the observations made with Rod I., the apparatus having been taken to pieces and put together again; the rod also being turned, and four springs being used.

Nos. 6 & 7, the observations made with Rod II., with four springs.

No. 8, the observations made with Rod II., with four springs, rod turned, and apparatus readjusted.

Table II. gives some measurements which prove that the increment in length between

0° and 100° may be considered for these rods as proportional to increase of temperature.

No. 1. The observation T_2, a, and b was taken whilst heating the trough for Experiment No. 4, Table I.

No. 2. The observation T_2, a, and b was taken whilst heating the trough for Experiment No. 5, Table I.

No. 3. The observation T_2, a, and b was taken whilst heating the trough for Experiment No. 7, Table I.

No. 4. The observation T_2, a, and b was taken whilst heating the trough for Experiment No. 8, Table I.

It was not easy to obtain a constant temperature for T_2; the values for T_2 and a are therefore the mean of two or more readings.

TABLE I.

No.	T_1.	T_2.	T_3.	a.	b.	$\frac{100a}{T_2-T_1}$.	$\frac{100b}{T_2-T_3}$.
1.	18°·6	100°·3	17°·8	1·098	1·098	1·344	1·331
2.	17·8	100·2	18·1	1·092	1·090	1·325	1·328
3.	18·2	100·3	18·6	1·099	1·091	1·339	1·335
4.	19·2	100·0	18·6	1·073	1·078	1·328	1·324
5.	18·6	100·0	19·4	1·087	1·070	1·335	1·327
6.	18·6	100·6	18·8	1·091	1·084	1·330	1·325
7.	18·4	100·4	19·0	1·091	1·090	1·330	1·339
8.	20·6	100·5	19·4	1·069	1·072	1·337	1·332
						Mean .... 1·331	

TABLE II.

No.	T_1.	T_2.	T_3.	a.	b.	$\frac{100a}{T_2-T_1}$.	$\frac{100b}{T_3-T_2}$.
1.	19°·2	60°·7	100°·0	0·549	0·524	1·323	1·333
2.	18·6	63·4	100·0	0·598	0·489	1·335	1·336
3.	18·4	66·0	100·4	0·633	0·458	1·330	1·330
4.	20·6	59·2	100·5	0·512	0·557	1·326	1·349

T_1, T_2, T_3 denote the true temperature of the water.

a and b, the true expansion of the rod between those temperatures, expressed in millimetres.

The last two columns give the expansion of the rods, calculated from the respective observations for 100°.

The length of the two rods was the same, namely 1825 millimetres, and their diameter about 20 millimetres.

The increment in length for 1 metre will be therefore between 0° and 100°,

$$0^{m}{\cdot}729;$$

or the formula for the correction of the linear expansion of the glass rods will be

$$L_t=L_0(1+0\cdot00000729t),$$

and for the cubical expansion,

$$V_t=V_0(1+0\cdot00002187t).$$

In carrying out the foregoing experiments an interesting observation was made; when the glass rod was heated in the morning for the first determination, the value deduced for the expansion of the rod was greater than those obtained afterwards on the same day—a result which proves that the rod, on being heated, only resumes its normal length after a certain time, and that this gradual change in length is perceptible after twelve to fifteen hours. Table III. gives a few examples of this fact.

TABLE III.

No.	T_1.	T_2.	T_3.	a.	b.	$\frac{100a}{T_2-T_1}$.	$\frac{100b}{T_2-T_3}$.
1.	19°·6	100°·5	19°·0	1·110	1·085	1·372	1·331
2.	17·4	100·3	18·8	1·133	1·090	1·367	1·337
3.	17·2	100·5	18·8	1·138	1·089	1·366	1·333
4.	18·2	100·0	19·0	1·126	1·087	1·376	1·342

From the above the mean expansion of the rod on first heating between 0° and 100° is

1·370.

The mean of the experiments given in Table I. is

1·331,

making a difference of about 3 per cent. on the expansion*.

II. *On the Method employed for the Determination of the Cubical Expansion of Water and Mercury.*

Fig. 5 shows the arrangement of the apparatus used for the determinations.

Through a small hole in the bottom of the balance and shelf a platinum wire hung from the small pan above. The diameter of the wire is about 0·5 millim. To this wire, by means of a hook, the metal was suspended by a finer wire (0·04 millim. diameter) in the water contained in the box below. The size of the box, measured inside, was 200 millims. cube. It was made of zinc, double sided, and encased in wood. The covers were cut in two to allow them to be put on or taken off without disturbing the fine wire. Through these, holes were made (fig. 6), *a*, *a* for the stirrer, *b* for the draft pipe, *c* for the fine wire, and *d* for the thermometer. The stirrer was a square piece of sheet zinc, soldered to the end of the copper wires R, R, with a hole cut in the middle of it to make room for the cylinder *a*. The wires R, R, as shown in fig. 5, were connected together by a stout wire and binding screws. The draft-pipe *b*, figs. 5, 6 (of zinc tubing soldered to the one-half of the cover joining at *e* with *b*), served to draw off the steam formed at high temperatures, thereby preventing its condensation on the platinum wire. This was accomplished by leading the end of the pipe into a chimney and creating a draft by lighting a gas-burner in it. It was found by experiments at low temperature that creating this draft had not the slightest influence on the weighings, for those made with and without it were exactly the same.

---

* The rods must have been well annealed, for they stood sudden changes of temperature remarkably well, as shown by the process employed for cooling the water in the trough.

In the middle of the box stands the silver cylinder *a*, filled with distilled water, and in this the metal or glass was weighed. As seen in the figure, the thermometer-bulb stands in the same level as the metal. To prevent the evaporation of water by the current of air sucked in at *e* by the draft-pipe, as well as to hinder particles of dust falling into the water, the cylinder was covered with a platinum cover, *f*, *f* (divided in two), with two holes, the one for the fine wire, the other for the thermometer*. The water in the box was heated by steam, the pipe surrounding the cylinder, a small screen of sheet zinc bent outwards being placed between them to prevent the steam coming in direct contact with the cylinder. The general method of observing with this apparatus was as follows:—The substance to be experimented on was cast or ground to a form somewhat like fig. 7, and suspended by means of a slip-knot made with the fine platinum wire in the cylinder filled with boiling distilled water. This being made to boil, was boiled with the substance for the space of half an hour. Another silver vessel was kept ready with boiled out and boiling water to supply the loss by evaporation. After boiling for the half hour, the cylinder was placed in the box already filled with water of the proper temperature, and the platinum covers placed on it; the box was then covered with the zinc and wooden covers, of course great care being taken to let the fine wire swing freely. Whilst experimenting at high temperatures, steam had to be passed into the box to keep a constant temperature. By means of a small boiler, heated by gas placed at some distance from the apparatus, this was easily effected. In fact, by carefully regulating the gas, any temperature between 50° and 100° may be kept constant for any time. A waste-pipe was fitted into the side of the box to allow the water when it reached a certain level to flow away; as soon as the temperature became constant, the first weighing was proceeded with; in the one pan of the balance, large weights were placed so as to make that side of the balance the heaviest; this is brought into equilibrium by placing smaller weights in the other pan, namely, the one to which the platinum wire is fixed. The balance stands in a glass case, and surrounding this is another glass case (not shown in the figure), to keep the temperature of the balance as constant as possible. It did not vary during a series of observations more than 1°. The proper weight having been found, which it was possible to do to an accuracy of 0·0001 grm. when weighing in water, it was noted, together with the temperatures of the thermometers, the one (T) in the box, that (T_1) reaching halfway up the exposed column, and the one in the balance-case. These thermometers were connected as already described in Part I. The thermometer (T) in the box was read off at a distance by a second observer through a telescope. All these data being noted down, a second and third weighing was made, and as the temperature only altered one- or two-tenths of a degree during the time, it was easily seen whether the weighings agreed with each other; and if this were not the case, fresh weighings were made, and often when these again did not agree, it was found that a small particle of dust had attached itself to the wire in the water; in fact this occurs very often, so that, after the weighings are finished, great care was taken to see whether any dust was hanging to the fine wire. Having finished the observations at the one temperature, the cylinder was taken out of the box, the water brought to boil, and kept boiling again for half an hour, and in the same manner as before, the weighings, &c. repeated, and so on for each different temperature.

---

* To diminish the amount of air sucked in at *e*, and as a protection againt dust, the opening at *e* was covered with a piece of zinc cut as shown in fig. 8, the hole in the centre having about 2 millimetres diameter.

The balance was carefully adjusted, so that 50 grms. in each pan might be changed without showing the slightest difference in weight. The weights were from time to time compared with each; the 50 grms. being correct according to the Kew Standard, any alteration found in the smaller weights was allowed for. At least once a day, and with some experiments after each observation, the barometer and thermometer placed by its side were read off for the reduction of weights to *vacuum*.

The dipping in and out of the water the fine platinum wire did not influence the weighings at all; wires of somewhat larger diameter could not be used, as with these appreciable differences were observed. As the weight of a metre of the fine platinum wire was only 0·06 grm., the error caused by the wire dipping in the water may be neglected, it being so small, as only 60 to 70 millimeters dipt in the water (forming the slip-knot, &c.). These weigh about 0·004 grm., and they would lose in water 0·0002 grm.; but as we only have to deal with the differences of loss of weight in water at different temperatures, these 0·0002 grm. will alter in volume between 0° and 100° to such an unmeasurable extent that they need not enter into the calculations. The column of mercury in the thermometer (T) not immersed in the water was corrected for as described in Part I.

III. *On the Redetermination of the Coefficients of Expansion of Water.*

To determine the coefficients of the expansion of water, the pieces of glass cut from the ends of the rods and ground to the shape of a double wedge were weighed in water at different temperatures. The pieces were highly polished, and at one end notches were ground in to give a hold to the platinum wire.

Between each of the observations at different temperatures the water in the cylinder was reboiled to drive out any air which might have been absorbed during the time of weighing. The water employed was distilled from a copper still (tinned inside), the steam being condensed in a tin worm, and kept for use in a large glass bottle.

The results of the different weighings are contained in Tables IV., V., VI. (gramme weights, all weighings reduced to *vacuum*).

Table IV.—Experiments made with a piece of glass rod cut from Rod I. (Series I.)

Temperature.	Absolute loss of weight in water.	$\frac{1+at}{W_t}$.	Volume of water at t°.	Calculated.	Difference.
4°·00	15·4057	0·0649167	1·000000	1·000000	0·000000
6·60	15·4057	0·0649204	1·000057	1·000055	+0·000002
12·25	15·4005	0·0649504	1·000518	1·000525	−0·000007
16·70	15·3917	0·0649939	1·001189	1·001177	+0·000012
20·45	15·3822	0·0650393	1·001888	1·001889	−0·000001
23·10	15·3730	0·0650820	1·002546		
24·80	15·3679	0·0651060	1·002915		
27·10	15·3592	0·0651461	1·003534		
32·85	15·3353	0·0652559	1·005224		
43·25	15·2808	0·0655035	1·009039		
44·50	15·2736	0·0655362	1·009544		
48·90	15·2452	0·0656646	1·011520		
61·00	15·1588	0·0660563	1·017555		
74·50	15·0487	0·0665685	1·025443		
85·10	14·9584	0·0670216	1·032424		
98·70	14·8126	0·0676558	1·042194		

Table V.—Experiments made with a second piece of glass rod cut from Rod I. (Series II.)

Temperature.	Absolute loss of weight in water.	$\frac{1+at}{W_t}$.	Volume of water at t°.
5°·35	15·7327	0·0635693	1·000015
8·45	15·7317	0·0635775	1·000144
19·75	15·7113	0·0636757	1·001689
30·45	15·6716	0·0638520	1·004463
50·80	15·5558	0·0643561	1·012393
73·30	15·3776	0·0651340	1·024628
86·40	15·2542	0·0656794	1·033209
94·30	15·1721	0·0660462	1·038980

Table VI.—Experiments made with a piece of glass rod cut from Rod II. (Series III.).

Temperature.	Absolute loss of weight in water.	$\frac{1+at}{W_t}$.	Volume of water at t°.
8°·90	11·3425	0·0881812	1·000192
20·90	11·3258	0·0883344	1·001929
32·35	11·2934	0·0886099	1·005055
46·40	11·2376	0·0890769	1·010352
60·40	11·1661	0·0896751	1·017136
70·35	11·1067	0·0901744	1·022799
86·80	10·9957	0·0911173	1·033495
98·40	10·9096	0·0918596	1·041926

In the first column the corrected temperatures are given; in the second the numbers express in grammes the loss of weight in water, or the difference between the weight of the piece of glass rod *in vacuo* and in water at the different temperatures. In the third the numbers represent those proportional to the volumes of waters displaced at the different temperatures. These values were arrived at in the following manner:—

Let a be the coefficient of the cubical expansion of the glass rod*, and V_0 its volume at 0°. Its volume at $t°$ will of course be $V_0(1+at)$. But this is likewise the volume of the displaced water whose weight, say W_t, is determined by experiment. Hence

$$\frac{V_0(1+at)}{W_t}$$

is the volume, at $t°$, of the unit of weight of water; or more generally *the volume of a given weight of water is proportional to*

$$\frac{1+at}{W_t}.$$

In the fourth column the volume of water is taken at 4 equal to 1° (Table IV.); and to reduce the values in Tables V. and VI. to the same unit, a formula was calculated from the first five observations in Series I. Table IV. to express the expansion of water between 4° and 20°·4.

The formula from which the calculated values (Table IV.) were obtained was

$$V_t=1+0\cdot0000084465(t-4)^2-0\cdot00000008900(t-4)^3,$$

and calculating from this formula the volumes at 5°·35 and 8°·90, and taking them equal to the values found for the numbers proportional to the volumes of water at the same temperatures in Series II. and III. (Tables V. and VI.), we reduce these volumes of water at different temperatures to the same unit.

Table VII. contains the values thus obtained for the expansion of water from the three series.

---

* $a=0\cdot00002187$. The coefficient here used must naturally be that obtained for the glass rods after having been heated, for the pieces were boiled with the water before the weighings were made.

TABLE VII.

Series.	Temperature $=t$.	Observed volume of water at $t^{\circ}=V_t$.	Calculated volume of water.	Difference.
1	4·00	1·000000	1·000000	0·000000
2	5·35	1·000015	1·000012	+0·000003
1	6·60	1·000057	1·000049	+0·000008
2	8·45	1·000144	1·000149	−0·000005
3	8·90	1·000192	1·000181	+0·000011
1	12·25	1·000518	1·000510	+0·000008
1	16·70	1·001189	1·001175	+0·000014
2	19·75	1·001689	1·001762	−0·000073
1	20·45	1·001888	1·001911	−0·000023
3	20·90	1·001929	1·002007	−0·000078
1	23·10	1·002546	1·002512	+0·000034
1	24·80	1·002915	1·002932	−0·000017
1	27·10	1·003534	1·003534	0·000000
2	30·45	1·004463	1·004475	−0·000012
3	32·35	1·005055	1·005041	+0·000014
1	32·85	1·005224	1·005201	+0·000023
1	43·25	1·009039	1·009020	+0·000019
1	40·50	1·009544	1·009540	+0·000004
3	46·40	1·010352	1·010352	0·000000
1	48·90	1·011520	1·011464	+0·000056
2	50·80	1·012393	1·012342	+0·000051
3	60·40	1·017136	1·017178	−0·000042
1	61·00	1·017555	1·017502	+0·000053
3	70·35	1·022799	1·022858	−0·000059
2	73·30	1·024628	1·024662	−0·000034
1	74·50	1·025443	1·025413	+0·000030
1	85·10	1·032424	1·032387	+0·000037
2	86·40	1·033209	1·033284	−0·000075
3	86·80	1·033495	1·033561	−0·000066
2	94·30	1·038980	1·038917	+0·000063
3	98·40	1·041926	1·041964	−0·000038
1	98·70	1·042194	1·042179	+0·000015

To express the volumes in one formula would require too many terms, as it was found by calculation that the following formulæ did not express the results with sufficient accuracy between 4° and 100°,

$$V_t = a + bt + ct^2 + dt^3,$$

$$V_t = 1 + a(t-4) + b(t-4)^2 + c(t-4)^3 + d(t-4)^4.$$

I therefore employed two formulæ to express the expansion of water between 4° and 100°, the first for temperatures between 4° and 32°, being

$$V_t = 1 - 0{\cdot}0000025300(t-4) + 0{\cdot}00000083890(t-4)^2 - 0{\cdot}0000000717 3(t-4)^3,$$

the second for temperatures between 32° and 100°,

$$V_t = 0{\cdot}999695 + 0{\cdot}0000054724t^2 - 0{\cdot}000000011260t^3.$$

In calculating the first formula, the observations at 19°·75 and 20°·90 were omitted, as by previous calculations they were found to be faulty. To prove that the impurities contained in the water used for the foregoing experiments have no influence on the results, a short series was made with common water. I do not, however, intend to convey the idea that the water was not pure in the ordinary acceptation of the word, as it was carefully distilled, but those who have tried to prepare absolutely chemically pure water know how difficult it is to prepare it in such a state, that it does not on evaporation leave a slight residue.

From KREMER'S experiments on the expansion of solutions of salts in water, it appears that even large percentages have only a slight influence on the coefficients of expansion of the water in which they are dissolved. Table VIII. contains some examples.

TABLE VIII.

T.	Volume.	T.	Volume.	T.	Volume.	T.	Volume.	T.	Volume.	T.	Volume.
(1) 19°·5	1·00000	(2) 19°·5	1·00000	(3) 19°·5	1·00000	(4) 19°·5	1·00000	(5) 19°·5	1·00000	(6) 19°·5	1·00000
100	1·04135	100	1·04144	100	1·04179	100·0	1·04217	100·0	1·04135	100·0	1·04138

(1) Expansion of water between 19°·5 and 100°*.[1]

(2) Expansion of water containing in 100 parts 5·2 parts of chloride of potassium †.

(3) „ „ „ „ 4·7 „ chloride of sodium †.

(4) „ „ „ „ 7·5 „ sulphate of sodium *.

(5) „ „ „ „ 5·1 „ sulphate of potassium *.

(6) Expansion of water, calculated from the above formulæ, taking the volume at 19·5, equal to 1·00000.

For the series contained in Table IX. common water was used. Water from the laboratory tap was well boiled to precipitate the carbonates held in solution by the free carbonic acid, filtered and mixed with 25 per cent. of distilled water, to prevent any precipitation of salt on boiling to drive out the absorbed air; in fact these 25 per cent. were added to replace the loss by evaporation. The determinations with this water were carried out in the usual manner; the piece of glass employed was the same as that used for Series 3.

TABLE IX.

T.	Absolute loss of weight in water.	$\frac{1+at'}{W_t}$.	Volumes of water at	Calculated volumes of water.	Difference.
20°·70	11·3259	0·0883333	1·001964	1·001964	
55·65	11·1916	0·0894614	1·014759	1·014703	+0·000056
95·90	10·9292	0·0916900	1·040040	1·040992	−0·000052

The calculated volumes have been deduced from the above formulæ; the observed value in the second column at 20°·7 being taken equal the calculated one in order to compare the other two values with those obtained from the experiments made with pure water.

For the convenience of experimenters, I give in Table X. the volume occupied by water from degree to degree, taking that at 4°=1·000000, as well as the differences for each degree.

---

* Pogg. Ann. cxiv. 41.

† *Ibid.* c. 394.

The temperature 32° used as the point of junction between the two formulæ was found by solving the equation

$$1-0{\cdot}0000025300(t-4)+0{\cdot}00000083890(t-4)^2-0{\cdot}00000007173(t-4)^3$$
$$=0{\cdot}999695+0{\cdot}0000054724t^2-0{\cdot}000000011260t^3,$$

whence $t=32°$.

By the first the volume at 32°=1·004932.

By the second the volume at 32°=1·004930.

The mean of these values is given in the Table.

TABLE X.

T.	Volume.	Difference per 1°.	T.	Volume.	Difference per 1°.
4°	1·000000		53°	1·013391	0·000482
5	1·000006	0·000006	54	1·013879	488
6	1·000028	22	55	1·014376	497
7	1·000066	38	56	1·014879	503
8	1·000119	53	57	1·015390	511
9	1·000188	69	58	1·015907	517
10	1·000271	83	59	1·016432	525
11	1·000369	98	60	1·016964	532
12	1·000479	110	61	1·017505	538
13	1·000604	125	62	1·018047	545
14	1·000742	138	63	1·018596	552
15	1·000892	150	64	1·019158	559
16	1·001054	162	65	1·019724	566
17	1·001227	173	66	1·020296	572
18	1·001412	185	67	1·020874	578
19	1·001608	196	68	1·021459	585
20	1·001814	206	69	1·022050	591
21	1·002029	215	70	1·022648	598
22	1·002254	225	71	1·023252	604
23	1·002488	234	72	1·023861	609
24	1·002731	243	73	1·024477	616
25	1·002982	251	74	1·025099	622
26	1·003241	259	75	1·025727	628
27	1·003507	266	76	1·026361	634
28	1·003780	273	77	1·027000	639
29	1·004059	279	78	1·027646	646
30	1·004345	286	79	1·028296	650
31	1·004635	290	80	1·028953	657
32	1·004931	296	81	1·029615	662
33	1·005249	318	82	1·030283	668
34	1·005578	329	83	1·030956	673
35	1·005916	338	84	1·031634	678
36	1·006261	345	85	1·032318	684
37	1·006616	355	86	1·033007	689
38	1·006979	363	87	1·033701	694
39	1·007351	372	88	1·034400	699
40	1·007730	379	89	1·035104	704
41	1·008118	388	90	1·035813	709
42	1·008514	396	91	1·036527	714
43	1·008918	404	92	1·037245	718
44	1·009331	413	93	1·037969	724
45	1·009751	420	94	1·038697	728
46	1·010179	428	95	1·039429	732
47	1·010614	435	96	1·040166	737
48	1·011059	445	97	1·040907	741
49	1·011510	451	98	1·041653	746
50	1·011969	459	99	1·042404	751
51	1·012435	466	100	1·043159	0·000755
52	1·012909	0·000474			

For sake of comparison I have given in Table XI. the values obtained by different experimenters for the expansion of water, taking in all cases its volume at 4°=1·000000.

TABLE XI.

	Kopp[*].	Despretz[†].	Pierre[‡].	Hagen[§].	Matthiessen.
4°	1·000000	1·000000	1·000000	1·000000	1·000000
10	1·000247	1·000268	1·000271	1·000269	1·000271
15	1·000818	1·000875	1·000850	1·000849	1·000892
20	1·001690	1·001790	1·001717	1·001721	1·001814
30	1·004187	1·004330	1·004195	1·004250	1·004345
40	1·007654	1·007730	1·007636	1.007711	1·007730
50	1·011890	1·012050	1·011939	1·011994	1·011969
60	1·016715	1·016980	1·017243	1·017001	1·016964
70	1·022371	1·022550	1·023064	1·022675	1·022648
80	1·028707	1·028850	1·029486	1·028932	1·028953
90	1·035524	1·035660	1·036421	1·035715	1·035813
100	1·043114	1·043150	1·043777	1·042969	1·043159

KOPP, DESPRETZ, and PIERRE used the same methods for their determinations, namely, that of determining the expansion of water in glass vessels (dilatometers). HAGEN employed the weighing process, but at high temperatures took no special precautions to prevent his fine wire becoming slightly wetted by the steam condensing on its surface. This might account for his values at 90° and 100° falling below mine[‖].

As I shall have to speak of the above series after describing the experiments with mercury, I will postpone the remarks I have to make.

IV. *On the Redetermination of the Coefficient of Expansion of Mercury.*

The mercury employed for the following experiments was purified by treating the commercial metal with nitric acid, distilling it, again treating it with nitric acid, redistilling and keeping it till required for use under a solution of the protonitrate of mercury. When required for use it was again treated with nitric acid on a water-bath for some little time, thoroughly washed with distilled water, dried first on the water, and then heated over the naked flame.

To weigh the metal in water at different temperatures, small buckets (about 20 millims. long, 15 millims. wide) were made from the ends of thin test-tubes. Across the mouths of these a thin platinum wire was fused to serve as a handle, to which the very fine wire can be fastened.

---

[*] Pogg. Ann. xcii. 42.

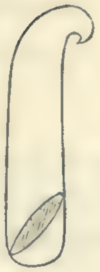
[†] Ann. de Chim. et de Phys. lxx. (1re série) 1.

[‡] Ann. de Chim. et de Phys. xv. (3me série) 325. Calculated by FRANKENHEIM, Pogg. Ann. lxxxvi. 451.

[§] Abhandlungen d. k. Akad. d. Wissensch. zu Berlin, 1855.

[‖] HENRICI and JOLLY's values (Bericht der k. bayer. Akad. der Wissens. 1864, 1 Heft 11, p. 141) are not quoted in the above Table, as they compared their thermometers with an air-thermometer, and do not give the differences between them; so their results are not comparable with those in the Table. I shall refer to this point in my paper on the expansion by heat of metals and alloys.

The coefficient of expansion of this sort of glass was determined by weighing a piece of the same tubing in water at low and high temperatures. The tube was drawn out and fused as shown in the annexed figure; but before sealing to, a small piece of lead was placed in the tube to cause it to sink in water. It was weighed in water with the following results:—



Temperature.	Absolute loss of weight in water.	$W_t(1+at)$.
11°·70	7·72250	7·72595
95·20	7·44775	7·74250

The values in the third column are deduced by multiplying the observed loss of weight in water by the volume occupied by water $(1+at)$ at the temperature at which the weighing was made (Table X.); for if the weights of water displaced be reduced to 4°, the numbers so obtained will express in cubic centimetres the volumes of glass at different temperatures.

The coefficient of expansion of the glass between 11°·7 and 95°·20 equals from the above values 0·002143, taking its volume at 11°·7=1,
or 0·002566 between 0° and 100°, taking its volume at 0°=1,
or the formula for the correction of the expansion of this sort of glass will be

$$V_t=V_0(1+0{\cdot}00002566t).$$

In carrying out the experiments with mercury, the bucket was first weighed in air, then placed in the silver cylinder and boiled in the water for about half an hour to free it from air; the mercury during the time being dried, as already mentioned, and still hot, was poured into the bucket, just lifted out, but quite full of water. In this manner it was possible to fill the bucket with mercury without air getting between it and the glass. After filling the bucket, the boiling was continued for a quarter of an hour, and then the observation made in the ordinary manner. Table XII. contains the five series made with different specimens of mercury used. To find the weight of the mercury after the weighings had been made, it was emptied into a crucible, dried on a water-bath, and weighed.

TABLE XII.

Temperature.	Loss of weight in water.	$W_t(1+at)$.	Volumes of glass.	Observed volumes of mercury.	Calculated volumes of mercury.	Difference.
Series I.						
4°·2	3·47615	3·47615	0·49900	2·97715	2·97704	+0·00011
47·3	3·46245	3·49965	0·49955	3·00010	3·00031	−0·00021
71·4	3·43280	3·51345	0·49990	3·01355	3·01333	+0·00022
95·4	3·39170	3·52640	0·50020	3·02620	3·02629	−0·00009
Series II.						
11·5	3·69250	3·69405	0·49910	3·19495	3·19497	−0·00002
41·7	3·68090	3·71180	0·49935	3·21245	3·21243	+0·00002
69·3	3·64740	3·72850	0·49985	3·22865	2·22838	+0·00027
95·3	3·60060	3·74335	0·50020	3·24315	3·24347	−0·00032
Series III.						
6·5	3·54240	3·54255	0·49905	3·04350	3·04355	−0·00005
44·6	3·53020	3·56405	0·49950	3·06455	3·06449	+0·00006
67·9	3·50235	3·57730	0·49980	3·07750	3·07730	+0·00020
94·0	3·45780	3·59160	0·50015	3·09145	3·09164	−0·00019
Series IV.						
4·7	4·54765	4·54765	0·47250	4·07515	4·07522	−0·00007
34·4	4·54395	4·56990	0·47285	4·09705	4·09702	+0·00003
63·5	4·50700	4·59210	0·47320	4·11890	4·11844	+0·00046
95·3	4·43905	4·61505	0·47360	4·14145	4·14186	−0·00041
Series V.						
6·1	4·78140	4·78155	0·47255	4·30900	4·30901	−0·00001
47·5	4·76285	4·81445	0·47305	4·34140	4·34137	+0·00003
96·6	4·66395	4·85335	0·47365	4·37970	4·37974	−0·00004

The bucket used in Series I., II., and III. was the same. Its weight *in vacuo* was =1·2523 grm., and it lost in water at 11°·2, 0·4989 grm.

The bucket used in Series IV. and V. was the same. Its weight *in vacuo* was=1·750 grm., and it lost in water at 8°·6, 0·4725 grm.

Deducing from these determinations the volumes at 0°, we find that of the first to be =0·49895 cub. centim., and that of second to be =0·47245 cub. centim.

The formula therefore for the correction of the expansion of the first bucket used was

$$V_t=0·49895(1+0·00002566.t),$$

and that for the second

$$V_t=0·47245(1+0·00002566.t).$$

The volumes of the glass were subtracted from the volumes of the water displaced, to find the volumes of the mercury for

$$W_t(1+a_1t)=U_0(1+bt)+W_0(1+at),$$

where U_0 is the volume of mercury at 0°, b its coefficient of expansion, $W_t(1+a_1t)$ the volume of the water displaced, and $W_0(1+at)$ the volume of the bucket. Calculating the relative coefficients of expansion of mercury for each series, and deducing by means of these the volumes of the mercury at 0°, we arrive at the following formulæ:—

For Series I. $U_t=2{\cdot}97477+0{\cdot}0005400t$.
„ II. $U_t=3{\cdot}18832+0{\cdot}0003782t$.
„ III. $U_t=3{\cdot}03998+0{\cdot}0005496t$.
„ IV. $U_t=4{\cdot}07168+0{\cdot}0007364t$.
„ V. $U_t=4{\cdot}30424+0{\cdot}0007816t$.

It will be seen that the volumes calculated by these formulæ agree closely with those observed.

The above formulæ may, however, be written as follows:—

I. $U_t=2{\cdot}97477(1+0{\cdot}0001815t)$,
II. $U_t=3{\cdot}18832(1+0{\cdot}0001813t)$,
III. $U_t=3{\cdot}03998(1+0{\cdot}0001808t)$,
IV. $U_t=4{\cdot}07168(1+0{\cdot}0001808t)$,
V. $U_t=4{\cdot}30424(1+0{\cdot}0001816t)$,

where the coefficients are referred to the volumes of mercury at 0° equalling unity.

The mean of the coefficients is

$$0{\cdot}0001812,$$

a number closely agreeing with Regnault's, namely,

$$0{\cdot}0001815.$$

The above five series also prove that the air absorbed by the water during the time of weighing does not influence the results; for in Series I. the water in the cylinder was boiled (to free it from air) only once during the time of the observations, the weighings being made at the highest temperature first, and then on cooling the water gradually the other weighings were taken, the water in the box not being stirred at all.

In Series II. same remarks as for Series I.

In Series III. the water was twice boiled, namely, before taking the weighings at 94°·0 and 44°·6; otherwise same remarks as for Series I.

In Series IV. the water was twice boiled, namely, before taking the weighings at 95°·3 and 4°·7, and 63°·5 and 34°·4; the water in the box in which the cylinder stood being stirred during the weighings.

In Series V. the water was boiled before each observation, and the water in the box stirred during the time of weighing.

In the beginning of this paper I stated that my reason for carrying out the foregoing research was that, basing my calculations on KOPP'S coefficients of expansion of water, I could not obtain a value for the coefficient of mercury which agreed with REGNAULT'S.

If we deduce this value from Table XII., using KOPP'S coefficients, we find, of course taking the volume of water at 4°=1, the volume

$$U_t=U_0(1+0\cdot000178t).$$

The same deduced from calculations based on the values in Table X.,

$$U_t=U_0(1+0\cdot0001812t).$$

REGNAULT found by direct measurement the expansion of mercury to be

$$U_t=U_0(1+0\cdot0001815t).$$

On comparing the values given in Table XI., it will be seen how closely DESPRETZ'S and the last series agree, whereas KOPP'S and DESPRETZ'S results do not agree, although obtained by the same process. Bearing these facts in mind, we must conclude that KOPP'S coefficients for the expansion of water are too low, (1) as the coefficient of expansion of mercury falls below that found by REGNAULT when deduced by means of KOPP'S coefficient; (2) as the said coefficients are lower than those obtained by other observers; and (3) as the coefficient of mercury when deduced by means of those obtained for water by the above-mentioned observers agrees closely with that found by REGNAULT; for had I employed DESPRETZ'S coefficients instead of my own, I should have deduced very nearly the same value for the coefficient of expansion for mercury.

In conclusion I may be allowed to express my thanks to the gentlemen who have assisted in carrying out the foregoing research; to Professor HIRST for his kindness in suggesting methods of reduction and calculation, to Mr. BASSETT and Dr. MAX BEREND for the able manner in which they assisted in the experimental part, and to Dr. C. VOGT for his undertaking the greater part of the computations.

XIII. THE BAKERIAN LECTURE.—*On the Viscosity or Internal Friction of Air and other Gases.* *By* J. CLERK MAXWELL, *M.A.*, *F.R.S.*

Received November 23, 1865,—Read February 8, 1866.

THE gaseous form of matter is distinguished by the great simplification which occurs in the expression of the properties of matter when it passes into that state from the solid or liquid form. The simplicity of the relations between density, pressure, and temperature, and between the volume and the number of molecules, seems to indicate that the molecules of bodies, when in the gaseous state, are less impeded by any complicated mechanism than when they subside into the liquid or solid states. The investigation of other properties of matter is therefore likely to be more simple if we begin our research with matter in the form of a gas.

The viscosity of a body is the resistance which it offers to a continuous change of form, depending on the rate at which that change is effected.

All bodies are capable of having their form altered by the action of sufficient forces during a sufficient time. M. KOHLRAUSCH* has shown that torsion applied to glass fibres produces a permanent set which increases with the time of action of the force, and that when the force of torsion is removed the fibre slowly untwists, so as to do away with part of the set it had acquired. Softer solids exhibit the phenomena of plasticity in a greater degree; but the investigation of the relations between the forces and their effects is extremely difficult, as in most cases the state of the solid depends not only on the forces actually impressed on it, but on all the strains to which it has been subjected during its previous existence.

Professor W. THOMSON† has shown that something corresponding to internal friction takes place in the torsional vibrations of wires, but that it is much increased if the wire has been previously subjected to large vibrations. I have also found that, after heating a steel wire to a temperature below 120°, its elasticity was permanently diminished and its internal friction increased.

The viscosity of fluids has been investigated by passing them through capillary tubes‡, by swinging pendulums in them[*], and by the torsional vibrations of an immersed disk[†], and of a sphere filled with the fluid[‡].

---

* Ueber die elastische Nachwerkung bei der Torsion, Pogg. Ann. cxix. 1863.

† Proceedings of the Royal Society, May 18, 1865.

‡ Liquids: POISEUILLE, Mém. de Savants Étrangers, 1846. Gases: GRAHAM, Philosophical Transactions, 1846 and 1849.

The method of transpiration through tubes is very convenient, especially for comparative measurements, and in the hands of GRAHAM and POISEUILLE it has given good results, but the measurement of the diameter of the tube is difficult, and on account of the smallness of the bore we cannot be certain that the action between the molecules of the gas and those of the substance of the tube does not affect the result. The pendulum method is capable of great accuracy, and I believe that experiments are in progress by which its merits as a means of determining the properties of the resisting medium will be tested. The method of swinging a disk in the fluid is simple and direct. The chief difficulty is the determination of the motion of the fluid near the edge of the disk, which introduces very serious mathematical difficulties into the calculation of the result. The method with the sphere is free from the mathematical difficulty, but the weight of a properly constructed spherical shell makes it unsuitable for experiments on gases.

In the experiments on the viscosity of air and other gases which I propose to describe, I have employed the method of the torsional vibrations of disks, but instead of placing them in an open space, I have placed them each between two parallel fixed disks at a small but easily measurable distance, in which case, when the period of vibration is long, the mathematical difficulties of determining the motion of the fluid are greatly reduced. I have also used three disks instead of one, so that there are six surfaces exposed to friction, which may be reduced to two by placing the three disks in contact, without altering the weight of the whole or the time of vibration. The apparatus was constructed by Mr. BECKER, of Messrs. ELLIOTT Brothers, Strand.

Description of the Apparatus.

Plate XXI. fig. 1 represents the vacuum apparatus one-eighth of the actual size. M Q R S is a strong three-legged stool supporting the whole. The top (M M) is in the form of a ring. E E is a brass plate supported by the ring M M. The under surface is ground truly plane, the upper surface is strengthened by ribs cast in the same piece with it. The suspension-tube A C is screwed into the plate E E, and is 4 feet in height. The glass receiver N rests on a wooden ring P P with three projecting pieces which rest on the three brackets Q Q, of which two only are seen. The upper surfaces of the brackets and the under surfaces of the projections are so bevilled off, that by slightly turning the wooden ring in its own plane the receiver can be pressed up against the plate E E.

---

[*] BAILY, Phil. Trans. 1832; BESSEL, Berlin Acad. 1826; DUBUAT, Principes d'Hydraulique, 1786. All these are discussed in Professor STOKES's paper "On the Effect of the Internal Friction of Fluids on the Motion of Pendulums," Cambridge Phil. Trans. vol. ix. pt. 2 (1850).

[†] COULOMB, Mém. de l'Institut national, iii. p. 246; O. E. MEYER, Pogg. Ann. cxiii. (1861) p. 55, and Crelle's Journal, Bd. 59.

[‡] HELMHOLTZ and PIETROWSKI, Sitzungsberichte der k. k. Akad. April 1860.

F, G, H, K are circular plates of glass of the form represented in fig. 2. Each has a hole in the centre 2 inches in diameter, and three holes near the circumference, by which it is supported on the screws L L.

Fig. 6 represents the mode of supporting and adjusting the glass plates. L L is one of the screws fixed under the plate E E. S is a nut, of which the upper part fits easily in the hole in the glass plate F, while the under part is of larger diameter, so as to support the glass plate and afford the means of turning the nut easily by hand. These nuts occupy little space, and enable the glass disks to be brought very accurately to their proper position.

A C B, fig. 1, is a siphon barometer, closed at A and communicating with the interior of the suspension-tube at B. The scale is divided on both sides, so that the difference of the readings gives the pressure within the apparatus. T is a thermometer, lying on the upper glass plate. V is a vessel containing pumice-stone soaked in sulphuric acid, to dry the air. Another vessel, containing caustic potash, is not shown. D is a tube with a stopcock, leading to the air-pump or the gas-generator. C is a glass window, giving a view of the suspended mirror *d*.

For high and low temperatures the tin vessel (fig. 10) was used. When the receiver was exhausted, the ring P was removed, and the tin vessel raised so as to envelope the receiver, which then rested on the wooden support Y Y. The tin vessel itself rested, by means of projections, on the brackets Q Q. The outside of the tin vessel was then well wrapped up in blankets, and the top of the brass plate E E covered with a feather cushion; and cold water, hot water, or steam was made to flow through the tin vessel till the thermometer T, seen through the window W, became stationary.

The moveable parts of the apparatus consist of—

The suspension-piece *a*, fitting air-tight into the top of the tube and holding the suspension-wire by a clip, represented in fig. 5.

The axis *c d e k*, suspended to the wire by another clip at C.

The wire was a hard-drawn steel wire, one foot of which weighed 2·6 grains.

The axis carries the plane mirror *d*, by which its angular position is observed through the window C, and the three vibrating glass disks *f*, *g*, *h*, represented in fig. 3. Each disk is 10·56 inches diameter and about ·076 thick, and has a hole in the centre ·75 diameter. They are kept in position on the axis by means of short tubes of accurately known length, which support them on the axis and separate them from each other.

The whole suspended system weighs three pounds avoirdupois.

In erecting the apparatus, the lower part of the axis *e k* is screwed off. The fixed disks are then screwed on, with a vibrating disk lying between each. Tubes of the proper lengths are then placed on the lower part of the axis and between the disks. The axis is then passed up from below through the disks and tubes, and is screwed to the upper part at *e*. The vibrating disks are now hanging by the wire and in their proper places, and the fixed disks are brought to their proper distances from them by means of the adjusting nuts.

n s is a small piece of magnetized steel wire attached to the axis.

When it is desired to set the disks in motion, a battery of magnets is placed under N, and so moved as to bring the initial arc of vibration to the proper value.

Fig. 4 is a brass ring whose moment of inertia is known. It is placed centrically on the vibrating disk by means of three radial wires, which keep it exactly in its place.

Fig. 7 is a tube containing two nearly equal weights, which slide inside it, and whose position can be read off by verniers.

The ring and the tube are used in finding the moment of inertia of the vibrating apparatus.

The extent and duration of the vibrations are observed in the ordinary way by means of a telescope, which shows the reflexion of a scale in the mirror *d*. The scale is on a circular arc of six feet radius, concentric with the axis of the instrument. The extremities of the scale correspond to an arc of vibration of 19° 36′, and the divisions on the scale to 1′·7. The readings are usually taken to tenths of a division.

Method of Observation.

When the instrument was properly adjusted, a battery of magnets was placed on a board below N, and reversed at proper intervals till the arc of vibration extended slightly beyond the limits of the scale. The magnets were then removed, and any accidental pendulous oscillations of the suspended disks were checked by applying the hand to the suspension-tube. The barometer and thermometer were then read off, and the observer took his seat at the telescope and wrote down the extreme limits of each vibration as shown by the numbers on the scale. At intervals of five complete vibrations, the time of the transits of the middle point of the scale was observed (see Table I.). When the amplitude decreased rapidly, the observations were continued throughout the experiment; but when the decrement was small, the observer generally left the room for an hour, or till the amplitude was so far reduced as to furnish the most accurate results.

In observing a quantity which decreases in a geometrical ratio in equal times, the most accurate value of the rate of decrement will be deduced from a comparison of the initial values with values which are to these in the ratio of e to 1, where $e = 2{\cdot}71828$, the base of the Napierian system of logarithms. In practice, however, it is best to stop the experiment somewhat before the vibrations are so much reduced, as the time required would be better spent in beginning a new experiment.

In reducing the observations, the sum of every five maxima and of the consecutive five minima was taken, and the differences of these were written as the terms of the series the decrement of which was to be found.

In experiments where the law of decrement is uncertain, this rough method is inapplicable, and GAUSS's method must be applied; but the series of amplitudes in these experiments is so accurately geometrical, that no appreciable difference between the results of the two methods would occur.

The logarithm of each term of the series was then taken, and the mean logarithmic decrement ascertained by taking the difference of the first and last, of the second and last but one, and so on, multiplying each difference by the interval of the terms, and dividing the sum of the products by the sum of the squares of these intervals. Thus, if fifty observations were taken of the extreme limits of vibration, these were first combined by tens, so as to form five terms of a decreasing series. The logarithms of these terms were then taken. Twice the difference of the first and fifth of these logarithms was then added to the difference of the second and third, and the result divided by ten for the mean logarithmic decrement in five complete vibrations.

The times were then treated in the same way to get the mean time of five vibrations. The numbers representing the logarithmic decrement, and the time for five vibrations, were entered as the result of each experiment*.

The series found from ten different experiments were examined to discover any departure from uniformity in the logarithmic decrement depending on the amplitude of vibration. The logarithmic decrement was found to be constant in each experiment to within the limits of probable error; the deviations from uniformity were sometimes in one direction and sometimes in the opposite, and the ten experiments when combined gave no evidence of any law of increase or diminution of the logarithmic decrement as the amplitudes decrease. The forces which retard the disks are therefore as the first power of the velocity, and there is no evidence of any force varying with the square of the velocity, such as is produced when bodies move rapidly through the air. In these experiments the maximum velocity of the circumference of the moving disks was about $\frac{1}{12}$ inch per second. The changes of form in the air between the disks were therefore effected very slowly, and eddies were not produced†.

The retardation of the motion of the disks is, however, not due entirely to the action of the air, since the suspension wire has a viscosity of its own, which must be estimated separately. Professor W. Thomson has observed great changes in the viscosity of wires after being subjected to torsion and longitudinal strain. The wire used in these experiments had been hanging up for some months before, and had been set into torsional vibrations with various weights attached to it, to determine its moment of torsion. Its moment of torsion and its viscosity seem to have remained afterwards nearly constant, till steam was employed to heat the lower part of the apparatus. Its viscosity then increased, and its moment of torsion diminished permanently, but when the apparatus was again heated, no further change seems to have taken place. During each course of experiments, care was taken not to set the disks vibrating beyond the limits of the scale, so that the viscosity of the wire may be supposed constant in each set of experiments.

---

* See Table II.

† The total moment of the resistances never exceeded that of the weight of $\frac{1}{30}$ grain acting at the edge of the disks.

In order to determine how much of the total retardation of the motion is due to the viscosity of the wire, the moving disks were placed in contact with each other, and fixed disks were placed at a measured distance above and below them. The weight and moment of inertia of the system remained as before, but the part of the retardation of the motion due to the viscosity of the air was less, as there were only two surfaces exposed to the action of the air instead of six. Supposing the effect of the viscosity of the wire to remain as before, the difference of retardation is that due to the action of the four additional strata of air, and is independent of the value of the viscosity of the wire.

In the experiments which were used in determining the viscosity of air, five different arrangements were adopted.

Arrangement 1. Three disks in contact, fixed disks at 1 inch above and below.
„ 2. „ „ „ 0·5 inch.
„ 3. Three disks, each between two fixed disks at distance 0·683.
„ 4. „ „ „ „ „ 0·425.
„ 5. „ „ „ „ „ 0·18475.

By comparing the results of these different arrangements, the coefficient of viscosity was obtained, and the theory at the same time subjected to a rigorous test.

Definition of the Coefficient of Viscosity.

The final result of each set of experiments was to determine the value of the coefficient of viscosity of the gas in the apparatus. This coefficient may be best defined by considering a stratum of air between two parallel horizontal planes of indefinite extent, at a distance a from one another. Suppose the upper plane to be set in motion in a horizontal direction with a velocity of v feet per second, and to continue in motion till the air in the different parts of the stratum has taken up its final velocity, then the velocity of the air will increase uniformly as we pass from the lower plane to the upper. If the air in contact with the planes has the same velocity as the planes themselves, then the velocity will increase $\frac{v}{a}$ feet per second for every foot we ascend.

The friction between any two contiguous strata of air will then be equal to that between either surface and the air in contact with it. Suppose that this friction is equal to a tangential force f on every square foot, then

$$f=\mu\frac{v}{a},$$

where μ is the coefficient of viscosity, v the velocity of the upper plane, and a the distance between them.

If the experiment could be made with the two infinite planes as described, we should find μ at once, for

$$\mu=\frac{fa}{v}.$$

In the actual case the motion of the planes is rotatory instead of rectilinear, oscillatory instead of constant, and the planes are bounded instead of infinite.

It will be shown that the rotatory motion may be calculated on the same principles as rectilinear motion; but that the oscillatory character of the motion introduces the consideration of the inertia of the air in motion, which causes the middle portions of the stratum to lag behind, as is shown in fig. 8, where the curves represent the successive positions of a line of particles of air, which, if there were no motion, would be a straight line perpendicular to the planes.

The fact that the moving planes are bounded by a circular edge introduces another difficulty, depending on the motion of the air near the edge being different from that of the rest of the air.

The lines of equal motion of the air are shown in fig. 9.

The consideration of these two circumstances introduces certain corrections into the calculations, as will be shown hereafter.

In expressing the viscosity of the gas in absolute measure, the measures of all velocities, forces, &c. must be taken according to some consistent system of measurement.

If L, M, T represent the units of length, mass, and time, then the dimensions of f (a pressure per unit of surface) are $L^{-1}MT^{-2}$; a is a length, and v is a velocity whose dimensions are LT^{-1}, so that the dimensions of μ are $L^{-1}MT^{-1}$.

Thus if μ be the viscosity of a gas expressed in inch-grain-second measure, and μ' the same expressed in foot-pound-minute measure, then

$$\frac{\mu}{\mu'}\cdot\frac{1\text{ foot}}{1\text{ inch}}\cdot\frac{1\text{ pound}}{1\text{ grain}}\cdot\frac{1\text{ minute}}{1\text{ second}}=1.$$

According to the experiments of MM. HELMHOLTZ and PIETROWSKI*, the velocity of a fluid in contact with a surface is not always equal to that of the surface itself, but a certain amount of actual slipping takes place in certain cases between the surface and the fluid in immediate contact with it. In the case which we have been considering, if v_0 is the velocity of the fluid in contact with the fixed plane, and f the tangential force per unit of surface, then

$$f=\sigma v_0,$$

where σ is the coefficient of superficial friction between the fluid and the particular surface over which it flows, and depends on the nature of the surface as well as on that of the fluid. The coefficient σ is of the dimensions $L^{-2}MT^{-1}$. If v_1 be the velocity of the fluid in contact with the plane which is moving with velocity v, and if σ' be the coefficient of superficial friction for that plane,

$$f=\sigma'(v-v_1).$$

The internal friction of the fluid itself is

$$f=\frac{\mu}{a}(v_1-v_0).$$

---

* Sitzungsberichte der k. k. Akad. April 1860.

Hence

$$v=f\left(\frac{1}{\sigma}+\frac{1}{\sigma'}+\frac{a}{\mu}\right).$$

If we make $\frac{\mu}{\sigma}=\beta$, and $\frac{\mu}{\sigma'}=\beta'$, then

$$v=f\left(\frac{a+\beta+\beta'}{\mu}\right),$$

or the friction is equal to what it would have been if there had been no slipping, and if the interval between the planes had been increased by $\beta+\beta'$. By changing the interval between the planes, a may be made to vary while $\beta+\beta'$ remains constant, and thus the value of $\beta+\beta'$ may be determined. In the case of air, the amount of slipping is so small that it produces no appreciable effect on the results of experiments. In the case of glass surfaces rubbing on air, the probable value of β, deduced from the experiments, was $\beta=\cdot 0027$ inch. The distance between the moving surfaces cannot be measured so accurately as to give this value of β the character of an ascertained quantity. The probability is rather in favour of the theory that there is no slipping between air and glass, and that the value of β given above results from accidental discrepancy in the observations. I have therefore preferred to calculate the value of μ on the supposition that there is no slipping between the air and the glass in contact with it.

The value of μ depends on the nature of the gas and on its physical condition. By making experiments in gas of different densities, it is shown that μ remains constant, so that its value is the same for air at 0·5 inch and at 30 inches pressure, provided the temperature remains the same. This will be seen by examining Table IV., where the value of L, the logarithm of the decrement of arc in ten single vibrations, is the same for the same temperature, though the density is sixty times greater in some cases than in others. In fact the numbers in the column headed L′ were calculated on the hypothesis that the viscosity is independent of the density, and they agree very well with the observed values.

It will be seen, however, that the value of L rises and falls with the temperature, as given in the second column of Table IV. These temperatures range from 51° to 74° Fahr., and were the natural temperatures of the room on different days in May 1865. The results agree with the hypothesis that the viscosity is proportional to $(461°+\theta)$, the temperature measured from absolute zero of the air-thermometer. In order to test this proportionality, the temperature was raised to 185° Fahr. by a current of steam sent round the space between the glass receiver and the tin vessel. The temperature was kept up for several hours, till the thermometer in the receiver became stationary, before the disks were set in motion. The ratio of the upper temperature (185° F.) to the lower (51°), measured from −461° F., was

$$1\cdot 2605.$$

The ratio of the viscosity at the upper temperature to that at the lower was

$$1\cdot 2624,$$

which shows that the viscosity is proportional to the absolute temperature very nearly. The simplicity of the other known laws relating to gases warrants us in concluding that the viscosity is really proportional to the temperature, measured from the absolute zero of the air-thermometer.

These relations between the viscosity of air and its pressure and temperature are the more to be depended on, since they agree with the results deduced by Mr. GRAHAM from experiments on the transpiration of gases through tubes of small diameter. The constancy of the viscosity for all changes of density when the temperature is constant is a result of the Dynamical Theory of Gases *, whatever hypothesis we adopt as to the mode of action between the molecules when they come near one another. The relation between viscosity and temperature, however, requires us to make a particular assumption with respect to the force acting between the molecules. If the molecules act on one another only at a determinate distance by a kind of impact, the viscosity will be as the square root of the absolute temperature. This, however, is certainly not the actual law. If, as the experiments of GRAHAM and those of this paper show, the viscosity is as the first power of the absolute temperature, then in the dynamical theory, which is framed to explain the facts, we must assume that the force between two molecules is proportional inversely to the fifth power of the distance between them. The present paper, however, does not profess to give any explanation of the cause of the viscosity of air, but only to determine its value in different cases.

Experiments were made on a few other gases besides dry air.

Damp air, over water at 70° F. and 4 inches pressure, was found by the mean of three experiments to be about one-sixtieth part less viscous than dry air at the same temperature.

Dry hydrogen was found to be much less viscous than air, the ratio of its viscosity to that of air being ·5156.

A small proportion of air mixed with hydrogen was found to produce a large increase of viscosity, and a mixture of equal parts of air and hydrogen has a viscosity nearly equal to $\frac{15}{16}$ of that of air.

The ratio of the viscosity of dry carbonic acid to that of air was found to be ·859.

It appears from the experiments of Mr. GRAHAM that the ratio of the transpiration time of hydrogen to that of air is ·4855, and that of carbonic acid to air ·807. These numbers are both smaller than those of this paper. I think that the discrepancy arises from the gases being less pure in my experiments than in those of GRAHAM, owing to the difficulty of preventing air from leaking into the receiver during the preparation, desiccation, and admission of the gas, which always occupied at least an hour and a half before the experiment on the moving disks could be begun.

It appears to me that for comparative estimates of viscosity, the method of transpiration is the best, although the method here described is better adapted to determine the absolute value of the viscosity, and is less liable to the objection that in fine capillary

---

* "Illustrations of the Dynamical Theory of Gases," Philosophical Magazine, Jan. 1860.

tubes the influence of molecular action between the gas and the surface of the tube may possibly have some effect.

The actual value of the coefficient of viscosity in inch-grain-second measure, as determined by these experiments, is $\cdot00001492(461^\circ+\theta)$.

At 62° F. $\mu=\cdot007802$.

Professor **Stokes** has deduced from the experiments of **Baily** on pendulums

$$\sqrt{\frac{\mu}{\varrho}}=\cdot116,$$

which at ordinary pressures and temperatures gives

$$\mu=\cdot00417,$$

or not much more than half the value as here determined. I have not found any means of explaining this difference.

In metrical units and Centigrade degrees

$$\mu=\cdot01878(1+\cdot00365\theta).$$

M. O. E. **Meyer** gives as the value of μ in centimetres, grammes, and seconds, at 18° C.,

$$\cdot000360.$$

This, when reduced to metre-gramme-second measure, is

$$\mu=\cdot0360.$$

I make μ, at 18° C., $=\cdot0200$.

Hence the value given by **Meyer** is 1·8 times greater than that adopted in this paper.

M. **Meyer**, however, has a different method of taking account of the disturbance of the air near the edge of the disk from that given in this paper. He supposes that when the disk is very thin the effect due to the edge is proportional to the thickness, and he has given in **Crelle**'s 'Journal' a vindication of this supposition. I have not been able to obtain a mathematical solution of the case of a disk oscillating in a large extent of fluid, but it can easily be shown that there will be a finite increase of friction near the edge of the disk due to the want of continuity, even if the disk were infinitely thin. I think therefore that the difference between M. **Meyer**'s result and mine is to be accounted for, at least in part, by his having under-estimated the effect of the edge of the disk. The effect of the edge will be much less in water than in air, so that any deficiency in the correction will have less influence on the results for liquids which are given in M. **Meyer**'s very valuable paper.

Mathematical Theory of the Experiment.

A disk oscillates in its own plane about a vertical axis between two fixed horizontal disks, the amplitude of oscillation diminishing in geometrical progression, to find what part of the retardation is due to the viscosity of the air between it and the fixed disks.

That part of the surface of the disk which is not near the edge may be treated as part of an infinite disk, and we may assume that each horizontal stratum of the fluid oscillates as a whole. In fact, if the motion of every part of each stratum can be accounted for by the actions of the strata above and below it, there will be no mutual action between the parts of the stratum, and therefore no relative motion between its parts.

Let θ be the angle which defines the angular position of the stratum which is at the distance y from the fixed disk, and let r be the distance of a point of that stratum from the axis, then its velocity will be $r\frac{d\theta}{dt}$, and the tangential force on its lower surface arising from viscosity will be on unit of surface

$$-\mu r\frac{d^2\theta}{dydt}=f. \qquad (1)$$

The tangential force on the upper surface will be

$$\mu r\left(\frac{d^2\theta}{dydt}+\frac{d^3\theta}{dy^2dt}dy\right);$$

and the mass of the stratum per unit of surface is ϱdy, so that the equation of motion of each stratum is

$$\varrho\frac{d^2\theta}{dt^2}=\mu\frac{d^3\theta}{dy^2dt}, \qquad (2)$$

which is independent of r, showing that the stratum moves as a whole.

The conditions to be satisfied are, that when $y=0$, $\theta=0$; and that when $y=b$,

$$\theta=\mathrm{C}e^{-lt}\cos(nt+\alpha). \qquad (3)$$

The disk is suspended by a wire whose elasticity of torsion is such that the moment of torsion due to a torsion θ is $\mathrm{I}\omega^2\theta$, where I is the moment of inertia of the disks. The viscosity of the wire is such that an angular velocity $\frac{d\theta}{dt}$ is resisted by a moment $2\mathrm{I}k\frac{d\theta}{dt}$. The equation of motion of the disks is then

$$\mathrm{I}\left(\frac{d^2\theta}{dt^2}+2k\frac{d\theta}{dt}+\omega^2\theta\right)+\mathrm{NA}\mu\frac{d^2\theta}{dydt}=0, \qquad (4)$$

where $\mathrm{A}=\int 2\pi r^3dr=\frac{1}{2}\pi r^4$, the moment of inertia of each surface, and N is the number of surfaces exposed to friction of air.

The equation for the motion of the air may be satisfied by the solution

$$\theta=e^{-lt}\{e^{py}\cos(nt+qy)-e^{-py}\cos(nt-qy)\}, \qquad (5)$$

provided

$$2pq=\frac{\varrho n}{\mu}, \qquad (6)$$

and

$$p^2-q^2=\frac{\varrho l}{\mu}; \qquad (7)$$

and in order to fulfil the conditions (3) and (4),

$$2\mathrm{I}n(l-k)(e^{2pb}+e^{-2pb}-2\cos 2qb)=\mathrm{NA}\mu\{(pn-lq)(e^{2pb}-e^{-2pb})+(qn+lp)2\sin 2qb\}. \quad . \qquad (8)$$

Expanding the exponential and circular functions, we find

$$2\mathrm{I}b(l-k)=\mathrm{NA}\mu\{1-\tfrac{1}{\underline{|3}}cl+\tfrac{1}{\underline{|6}}c^2(n^2-3l^2)+\tfrac{1}{\underline{|7}}\tfrac{2}{3}c^3(n^2l-l^3)+\tfrac{1}{\underline{|10}}c^4(\tfrac{7}{16}n^4+\tfrac{215}{16}n^2l^2-\tfrac{145}{4}l^4)\}, \quad (9)$$

where $c=\dfrac{4b^2\varrho}{\mu}$,

$l=$ observed Napierian logarithmic decrement of the amplitude in unit of time,

$k=$ the part of the decrement due to the viscosity of the wire.

When the oscillations are slow as in these experiments, when the disks are near one another, and when the density is small and the viscosity large, the series on the right-hand side of the equation is rapidly convergent.

When the time from rest to rest was thirty-six seconds, and the interval between the disks 1 inch, then for air of pressure 29·9 inches, the successive terms of the series were

$$1{\cdot}0-0{\cdot}00508 \quad +0{\cdot}24866 \quad +0{\cdot}00072 \quad +0{\cdot}00386=1{\cdot}24816;$$

but when the pressure was reduced to 1·44 inch, the series became

$$1{\cdot}0-0{\cdot}0002448 \quad +{\cdot}0005768+{\cdot}00000008 \quad +00000002=1{\cdot}0003321.$$

The series is also made convergent by diminishing the distance between the disks. When the distance was ·1847 inch, the first two terms only were sensible. When the pressure was 29·29, the series was

$$1-{\cdot}000858 \quad +{\cdot}000278=1-{\cdot}00058.$$

At smaller pressures the series became sensibly=1.

The motion of the air between the two disks is represented in fig. 8, where the upper disk is supposed fixed and the lower one oscillates. A row of particles of air which when at rest form a straight line perpendicular to the disks, will when in motion assume in succession the forms of the curves 1, 2, 3, 4, 5, 6. If the ratio of the density to the viscosity of the air is very small, or if the time of oscillation is very great, or if the interval between the disks is very small, these curves approach more and more nearly to the form of straight lines.

The chief mathematical difficulty in treating the case of the moving disks arises from the necessity of determining the motion of the air in the neighbourhood of the edge of the disk. If the disk were accompanied in its motion by an indefinite plane ring surrounding it and forming a continuation of its surface, the motion of the air would be the same as if the disk were of indefinite extent; but if the ring were removed, the motion of the air in the neighbourhood of the edge would be diminished, and therefore the effect of its viscosity on the parts of the disk near the edge would be increased. The actual effect of the air on the disk may be considered equal to that on a disk of greater radius forming part of an infinite plane.

Since the correction we have to consider is confined to the space immediately surrounding the edge of the disk, we may treat the edge as if it were the straight edge of an infinite plane parallel to xz, oscillating in the direction of z between two planes infinite in every direction at distance b. Let w be the velocity of the fluid in the direction of z, then the equation of motion is*

$$\varrho\frac{dw}{dt}=\mu\left(\frac{d^2w}{dx^2}+\frac{d^2w}{dy^2}\right), \quad \dots \quad (10)$$

with the conditions

$$w=0 \text{ when } y=\pm b, \quad \dots \quad (11)$$

and

$$w=\mathrm{C}\cos nt \text{ when } y=0, \text{ and } x \text{ is positive.} \quad \dots \quad (12)$$

I have not succeeded in finding the solution of the equation as it stands, but in the actual experiments the time of oscillation is so long, and the space between the disks is so small, that we may neglect $\frac{b^2\varrho n}{\mu}$, and the equation is reduced to

$$\frac{d^2w}{dx^2}+\frac{d^2w}{dy^2}=0 \quad \dots \quad (13)$$

with the same conditions. For the method of treating these conditions I am indebted to Professor W. THOMSON, who has shown me how to transform these conditions into another set with which we are more familar, namely, $w=0$ when $x=0$, and $w=1$ when $y=0$, and x is greater than $+1$, and $w=-1$ when x is less than -1. In this case we know that the lines of equal values of w are hyperbolas, having their foci at the points $y=0$, $x=\pm 1$, and that the solution of the equation is

$$w=\frac{2}{\pi}\sin^{-1}\frac{r_1-r_2}{2}, \quad \dots \quad (14)$$

where r_1, r_2 are the distances from the foci.

If we put

$$\varphi=\frac{2}{\pi}\log\{\sqrt{(r_1+r_2)^2-4}+r_1+r_2\}, \quad \dots \quad (15)$$

then the lines for which φ is constant will be ellipses orthogonal to the hyperbolas, and

$$\frac{d^2\varphi}{dx^2}+\frac{d^2\varphi}{dy^2}=0; \quad \dots \quad (16)$$

and the resultant of the friction on any arc of a curve will be proportional to $\varphi_1-\varphi_0$, where φ_0 is the value of φ at the beginning, and φ_1 at the end of the given arc.

In the plane $y=0$, when x is very great, $\varphi=\frac{2}{\pi}\log 4x$, and when $x=1$, $\varphi=\frac{2}{\pi}\log 2$, so that the whole friction between $x=1$ and a very distant point is $\frac{2}{\pi}\log 2x$.

Now let w and φ be expressed in terms of r and θ, the polar coordinates with respect to the origin as the pole; then the conditions may be stated thus:

---

* Professor STOKES "On the Theories of the Internal Friction of Fluids in Motion, &c.," Cambridge Phil. Trans. vol. viii.

When $\theta=\pm\frac{\pi}{2}$, $w=0$. When $\theta=0$ and r greater than 1, $w=1$. When $\theta=\pi$ and r greater than 1, $w=-1$.

Now let x', y' be rectangular coordinates, and let

$$y'=\frac{2}{\pi}b\theta \text{ and } x'=\frac{2}{\pi}b\log r, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

and let w and ϕ be expressed in terms of x' and y'; the differential equations (13) and (16) will still be true; and when $y'=\pm b$, $w=0$, and when $y'=0$ and x' positive, $w=1$.

When x' is great, $\phi=\frac{x'}{b}+\frac{2}{\pi}\log 4$, and when $x=0$, $\phi=\frac{2}{\pi}\log 2$, so that the whole friction on the surface is

$$\frac{x'}{b}+\frac{2}{\pi}\log 2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

which is the same as if a portion whose breadth is $\frac{2b}{\pi}\log_e 2$ had been added to the surface at its edge.

The curves of equal velocity are represented in fig. 9 at u, v, w, x, y. They pass round the edge of the moving disk A B, and have a set of asymptotes U, V, W, X, Y, arranged at equal distances parallel to the disks.

The curves of equal friction are represented at o, p, q, r, s, t. The form of these curves approximates to that of straight lines as we pass to the left of the edge of the disk.

The dotted vertical straight lines O, P, Q, R, S, T represent the position of the corresponding lines of equal friction if the disk A B had been accompanied by an extension of its surface in the direction of B. The total friction on A B, or on any of the curves u, v, w, &c., is equal to that on a surface extending to the point C, on the supposition that the moving surface has an accompanying surface which completes the infinite plane.

In the actual case the moving disk is not a mere surface, but a plate of a certain thickness terminated by a slightly rounded edge. Its section may therefore be compared to the curve uu' rather than to the axis A B.

The total friction on the curve is still equal to that on a straight line extending to C, but the velocity corresponding to the curve u is less than that corresponding to the line A B.

If the thickness of the disk is 2β, and the distance between the fixed disks$=2b$, so that the distance of the surfaces is $b-\beta$, the breadth of the strip which must be supposed to be added to the surface at the edge will be

$$\alpha=\frac{2b}{\pi}\log_e 10\left\{\log_{10}2+\log_{10}\sin\frac{\pi(b-\beta)}{2b}\right\}^{*}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

In calculating the moment of friction on this strip, we must suppose it to be at the

---

[*] This result is applicable to the calculation of the electrical capacity of a condenser in the form of a disk between two larger disks at equal distance from it.

same distance from the axis as the actual edge of the disk. Instead of $A=\frac{\pi}{2}r^4$ in equation (9), we must therefore put $A=\frac{\pi}{2}r^4+2\pi r^3\alpha$, and instead of b we must put $b-\beta$.

The actual value of $\frac{\pi}{2}r^4$ for each surface in inches=1112·8.

The value of I in inches and grains was 175337.

It was determined by comparing the times of oscillation of the axis and disks without the little magnet, with the times of the brass ring (fig. 4) and of the tube and weights (fig. 7). Four different suspension wires were used in these experiments.

The following Table gives the numbers required for the calculation of each of the five arrangements of the disks.

Arrangement.	Case 1.	Case 2.	Case 3.	Case 4.	Case 5.
N=Number of surfaces	2	2	6	6	6
$b-\beta$=distance of surfaces	1·0	0·5	0·683	0·425	0·1847
$2\pi r^3\alpha$=effect of edge	446·09	235·0	292·95	186·7	86·1
A=whole moment of each surface ...	1558·9	1347·8	1405·75	1299·5	1198·9
$\frac{N}{2}\frac{A}{\log_e 1\cdot01b}$=Q=	·003815	·007398	·015110	·022448	·047640

If l is the Napierian logarithmic decrement per second, and L the observed decrement of the common logarithm (to base 10) of the arc in time T, then

$$L=lT\log_{10}e. \qquad (20)$$

If n is the coefficient of t in the periodic terms, and T the time of five complete vibrations,

$$nT=10\pi. \qquad (21)$$

Let

$$K=kT\log_{10}e, \qquad (22)$$

then K is the part of the observed logarithmic decrement due to the viscosity of the wire, the yielding of the instrument, and the friction of the air on the axis, and is the same for all experiments as long as the wire is unaltered.

Let μ_0 be the value of μ at temperature zero, μ that at any other temperature θ, then if μ is proportional to the temperature from absolute zero,

$$\mu=(1+\alpha\theta)\mu_0, \qquad (23)$$

where α is the coefficient of expansion of air per degree.

Equation (9) may now be written in the form

$$\mu_0Q(1+x)(1+\alpha\theta)T+K=L, \qquad (24)$$

where $1+x$ is the series in equation (9), x being in most cases small, and may be calculated from an approximate value of μ_0.

The values of Q are to be taken from the Table according to the arrangement of disks in the experiment.

In this way I have combined the results of forty experiments on dry air in order to determine the values of μ_0 and K. Seven of these had the first arrangement, six had the second, six the third, nine the fourth, and twelve the fifth.

The values of Q for the five cases are roughly in the proportions of 1, 2, 4, 6, 12, so that it is easy to eliminate K and find μ_0. I had reason, however, to believe that the value of K was altered at a certain stage of the experiments when steam was first used to heat the air in the receiver. I therefore introduced two values of K, K_1 and K_2, into the experiments before and after this change respectively. The values of K_1 and K_2 deduced from these experiments were

In ten single vibrations.

$$K_1 = \cdot 01568$$

$$K_2 = \cdot 01901$$

The value of μ in inch-grain-second measure at temperature θ° FAHRENHEIT is for air

$$\mu = \cdot 00001492(461^\circ + \theta^\circ).$$

The value of L was then calculated for each experiment and compared with the observed value. In this way the error of mean square of a single experiment was found. The probable error of μ, as determined from the equations, was calculated from this and found to be 0·36 per cent. of its value.

In order to estimate the value of the evidence in favour of there being a finite amount of slipping between the disks and the air in contact with them, the value of L for each of the forty experiments was found on the supposition that

$$\beta = \cdot 0027 \text{ inch and } \mu = (\cdot 000015419)(461^\circ + \theta^\circ).$$

The error of mean square for each observation was found to be slightly greater than in the former case; the probable error of β was 40 per cent., and that of $\mu = 1 \cdot 6$ per cent.

I have no doubt that the true value of β is zero, that is, there is no slipping, and that the original value of μ is the best.

As the actual observations were very numerous, and the reduction of them would occupy a considerable space in this paper, I have given a specimen of the actual working of one experiment.

Table I. shows the readings of the scale as taken down at the time of observation, with the times of transit of the middle point of the scale after the fifth and sixth readings, with the sum of ten successive amplitudes deduced therefrom.

Table II. shows the results of this operation as extended to the rest of experiment 62, and gives the logarithmic decrement for each successive period of ten semivibrations, with the mean time and corresponding mean logarithmic decrement.

Table III. shows the method of combining forty experiments of different kinds. The observed decrement depends on two unknown quantities, the viscosity of air and that of the wire.

The experiments are grouped together according to the coefficients of μ and K that enter into them, and when the final results have been obtained, the decrements are calculated and compared with the results of observation. The calculated sums of the decrements are given in the last column.

Table IV. shows the results of the twelve experiments with the fifth arrangement. They are arranged in groups according to the pressure of the air, and it will be seen that the observed values of L are as independent of the pressure as the calculated values, in which the pressure is taken into account only in calculating the value of x in the fifth column. By arranging the values of $L-L'$ in order of temperature, it was found that within the range of atmospheric temperature during the course of the experiments the relation between the viscosity of air and its temperature does not perceptibly differ from that assumed in the calculation. Finally, the experiments were arranged in order of time, to determine whether the viscosity of the wire increased during the experiments, as it did when steam was first used to heat the apparatus. There did not appear any decided indication of any alteration in the wire.

Table V. gives the resultant value of μ in terms of the different units which are employed in scientific measurements.

Note, added February 6, 1866.—In the calculation of the results of the experiments, I made use of an erroneous value of the moment of inertia of the disks and axis$=1\cdot012$ of the true value, as determined by six series of experiments with four suspension wires and two kinds of auxiliary weights. The numbers in the coefficients of m in Table IV. are therefore all too large, and the value of μ is also too large in the same proportion, and should be

$$\mu=\cdot00001492(461^\circ+\theta).$$

The same error ran through all the absolute values in other parts of the paper as sent in to the Royal Society, but to save trouble to the reader I have corrected them where they occur.

TABLE I.—Experiment 62. Arrangement 5. Dry air at pressure 0·55 inch.
Temperature 68° F. May 9, 1865.

Greater scale reading.	Time. 3h+	Less scale reading.	Time.
	m s		m s
8309		1740	
8071	....	1968	
7852	27 42·4	2180	28 18·8
7650	....	2377	
7460	....	2561	
Sum of greater readings 39342	....	10826	
Sum of less do. 10826			
Difference 28516=sum of 10 amplitudes.			

The observations were continued in the same way till five sets of readings of this kind were obtained. The following were the results.

TABLE II.

Times.	Sum of ten amplitudes.	Logarithm.	Log. decrement.
h m s			
3 28 0·6	28516	4·4550886	0·1587745
34 3·2	19784	4·2963141	0·1585171
40 5·8	13734	4·1377970	0·1587041
46 8·6	9530	3·9790929	0·1596806
52 11·2	6598	3·8194123	

Results of experiment 62. Mean time of ten vibrations $=362{\cdot}66$

Mean log. decrement . . $=0{\cdot}1588574$.

TABLE III.

Equations from which μ for air was determined; $m=\dfrac{\mu}{461^{\circ}+\theta}$.

Number of experiments.	Arrangement.	Result of observation.	Result of calculation.
3.	1	$6{\cdot}3647\,m+3K_1=\cdot00023167$	·00022779
3.	2	$11{\cdot}2893\,m+3K_1=\cdot00028280$	·00030214
6.	4	$71{\cdot}2412\,m+6K_1=\cdot00135467$	·00133897
4.	1	$8{\cdot}7221\,m+4K_2=\cdot00034562$	·00034127
3.	2	$11{\cdot}6680\,m+3K_2=\cdot00031505$	·00033335
12.	5	$297{\cdot}7880\,m+12K_2=\cdot00511708$	·00512666
3.	4	$36{\cdot}0551\,m+3K_2=\cdot00069607$	·00070159
6.	3	$48{\cdot}8911\,m+6K_2=\cdot00108215$	·00105333

Final result $\mu^{*}=\cdot00001510\,(461^{\circ}+\theta)$ with probable error 0·36 per cent.

$K_1=\cdot0000439$, $K_2=\cdot0000524$.

TABLE IV.—Experiments with Arrangement 5.

No. of experiment.	Absolute temperature $461^{\circ}+\theta$.	Pressure, in inches of mercury.	Time of five double swings, in seconds.	Correction for inertia of air $(1+x)$ in equation (24).	L=decrement of logarithm of arc in ten single vibrations.		Diff. L−L′.
					L′ calculated.	L observed.	
62.	529	0·55	362·66	1−·0000157	·15719	·15886	+167
77.	516	0·50	362·80		·15378	·15260	−118
80.	527	0·56	364·04		·15648	·15946	+279
63.	527·5	5·57	362·72	1−·000157	·15680	·15628	− 52
64.	535	5·97	362·94		·15875	·15838	− 37
81.	516	5·52	363·80		·15379	·15389	+ 10
65.	524	25·58	362·64	1−·000486	·15555	·15422	−133
71.	513	19·87	362·50		·15299	·15144	−155
72.	514·5	20·31	362·86		·15338	·15269	− 69
75.	517	29·90	363·8	1−·00058	·15398	·15377	− 21
76.	512·5	29·76	362·89		·15280	·15146	−134
79.	521	28·22	363·9		·15502	·15510	+ 8

---

* This is the result derived from these equations, which is 1·2 per cent. too large.

TABLE V.—Results.

Coefficient of viscosity in dry air. Units—the inch, grain, and second, and FAHRENHEIT temperature, $\mu = \cdot00001492(461+\theta) = \cdot006876 + \cdot0001149\theta$.

At 60° F. the mean temperature of the experiments, $\mu = \cdot007763$. Taking the foot as unit instead of the inch, $\mu = \cdot000179(461+\theta)$. In metrical units (metre, gramme, second, and Centigrade temperature),

$$\mu = \cdot01878(1+\cdot00365\theta).$$

The coefficient of viscosity of other gases is to be found from that of air by multiplying μ by the ratio of the transpiration time of the gas to that of air as determined by GRAHAM*.

POSTSCRIPT.—Received December 7, 1865.

Since the above paper was communicated to the Royal Society, Professor STOKES has directed my attention to a more recent memoir of M. O. E. MEYER, "Ueber die innere Reibung der Gase," in Poggendorff's Annalen, cxxv. (1865). M. MEYER has compared the values of the coefficient of viscosity deduced from the experiments of BAILY by STOKES, with those deduced from the experiments of BESSEL and of GIRAULT. These values are ·000104, ·000275, and ·000384 respectively, the units being the centimetre, the gramme, and the second. M. MEYER'S own experiments were made by swinging three disks on a vertical axis in an air-tight vessel. The disks were sometimes placed in contact, and sometimes separate, so as to expose either two or six surfaces to the action of the air. The difference of the logarithmic decrement of oscillation in these two arrangements was employed to determine the viscosity of the air.

The effects of the resistance of the air on the axis, mirror, &c., and of the viscosity of the suspending wires are thus eliminated.

The calculations are made on the supposition that the moving disks are so far from each other and from the surface of the receiver which contains them, that the effect of the air upon each is the same as if it were in an infinite space.

At the distance of 30 millims., and with a period of oscillation of fourteen seconds, the mutual effect of the disks would be very small in air at the ordinary pressure. In November 1863 I made a series of experiments with an arrangement of three brass disks placed on a vertical axis exactly as in M. MEYER'S experiments, except that I had then no air-tight apparatus, and the disks were protected from currents of air by a wooden box only.

I attempted to determine the viscosity of air by means of the observed mutual action between the disks at various distances. I obtained the values of this mutual action for distances under 2 inches, but I found that the results were so much involved with the unknown motion of the air near the edge of the disks, that I could place no dependence on the results unless I had a complete mathematical theory of the motion near the edge.

* Philosophical Transactions, 1849.

In M. Meyer's experiments the time of vibration is shorter than in most of mine. This will diminish the effect of the edge in comparison with the total effect, but in rarefied air both the mutual action and the effect of the edge are much increased. In his calculations, however, the effect of the three edges of the disks is supposed to be the same, whether they are in contact or separated. This, I think, will account for the large value which he has obtained for the viscosity, and for the fact that with the brass disks which vibrate in 14 seconds, he finds the apparent viscosity diminish as the pressure diminishes, while with the glass disks which vibrate in 8 seconds it first increases and then diminishes.

M. Meyer concludes that the viscosity varies much less than the pressure, and that it increases slightly with increase of temperature. He finds the value of μ in metrical units (centimetre-gramme-second) at various temperatures,

Temperature.	Viscosity.
8°·3 C.	·000333
21°·5 C.	·000323
34°·4 C.	·000366

In my experiments, in which fixed disks are interposed between the moving ones, the calculation is not involved in so great difficulties; and the value of μ is deduced directly from the observations, whereas the experiments of M. Meyer give only the value of $\sqrt{\mu\varrho}$, from which μ must be determined. For these reasons I prefer the results deduced from experiments with fixed disks interposed between the moving ones.

M. Meyer has also given a mathematical theory of the internal friction of gases, founded on the dynamical theory of gases. I shall not say anything of this part of his paper, as I wish to confine myself to the results of experiment.

XIV. *Researches on Gun-cotton.—On the Manufacture and Composition of Gun-cotton.*

By F. A. Abel, *F.R.S.*, *V.P.C.S.*

Received April 10,—Read April 19, 1866.

The general designations of pyroxylin and gun-cotton have been applied, up to the present time, to the several products obtained by the action of nitric acid, either alone, or in admixture with sulphuric acid, upon cotton-wool. In the earlier papers on gun-cotton, published within a short period of the announcement (in 1846) of Schönbein's discovery of a substitute for gunpowder, the action of nitric acid upon cellulose was assumed by the several investigators to furnish one single definite product, to which different formulæ were assigned, based in some instances upon analytical results, in others upon the increase in weight sustained by the cotton on its treatment with nitric acid, or a mixture of nitric and sulphuric acids. Pélouze, who was the first to produce (in 1838) an explosive substance by the action of nitric acid on cellulose, originally believed this product to be identical with that which Braconnot obtained from starch by its solution in cold nitric acid and precipitation by water. But in November 1846 that chemist published the results of experiments establishing decided differences between the two bodies. The conclusion which Pélouze then arrived at, regarding the composition of pyroxylin, was founded upon the tolerably constant increase in weight (between 68 and 70 per cent.) of dry cotton-wool and paper, when submitted to the action of monohydrated nitric acid, either employed alone or mixed with an equal volume of concentrated sulphuric acid. He considered that nitric cellulose was the sole product of the reaction, and that it consisted of one equivalent of cellulose *minus* one equivalent of water, combined with two equivalents of monohydrated nitric acid, its formula being

$$C_{12}H_{11}O_{21}N_2\,(\mathrm{Є}_{12}H_{22}\mathrm{Ѳ}_{21}N_4).$$

Not long afterwards, Pélouze published conclusions varying somewhat from the preceding. He fixed the increase sustained by cellulose, upon its conversion into pyroxylin, at between 74 and 76 per cent., and was led by these numbers and by direct analytical data obtained with pyroxylin, to regard the formula

$$C_{24}H_{17}O_{17},\ 5NO_5\,(\mathrm{Є}_{12}H_{17}\mathrm{Ѳ}_{21}N_5)$$

as correctly representing the composition of that substance. The increase in weight which cellulose should sustain, by conversion into a substance of that composition, would be 74·9 per cent., a number which corresponds closely with the results obtained in these later experiments of Pélouze.

Numerous researches on the composition of pyroxylin were instituted by Continental and English chemists at about the period of Pélouze's experiments, and the following are some of the formulæ assigned by different experimenters to gun-cotton, in 1846 and 1847*:—

Pélouze (1846)	$C_{12}H_{11}N_2O_{21}= C_{12}H_9O_9, 2(HONO_5)$.
Péligot	$C_{12}H_9N_3O_{24}= C_{12}H_9O_9, 3NO_5$.
Von Kirchhoff and Reuter	$C_{12}H_9NO_{14}= C_{12}H_9O_9, NO_5$.
Fehling	$C_{12}H_{10}N_2O_{20}= C_{12}H_{10}O_{10}, 2NO_5$.
Porret and Teschemacher	$C_{24}H_{16}N_8O_{56}=2(C_{12}H_8O_8, 4NO_5)$.
Pélouze (1847)	$C_{24}H_{17}N_5O_{42}= C_{24}H_{17}O_{17}, 5NO_5$.
Schmidt and Hecker	$C_{12}H_5N_5O_{30}= C_{12}H_5O_5, 5NO_5$.
Gladstone	$C_{24}H_{15}N_5O_{40}= C_{24}H_{15}O_{20}, 5NO_4$.
W. Crum	$C_{12}H_7N_3O_{22}=\left\{\begin{array}{l} C_{12}H_7O_7, 3NO_5. \\ C_{12}H_7O_{10}, 3NO_4. \end{array}\right.$

Most of the published results of individual experimenters exhibit considerable variation among themselves, and in several instances the mean results are only approximately represented by the formula adopted.

The very considerable discrepancies presented by the results of independent investigations are unquestionably due, in part, to the difficulties which have to be encountered in attempts to obtain trustworthy analytical results from so highly explosive a material as gun-cotton. The methods of analysis which have been adopted have been almost as numerous as the formulæ deduced from their results; and in several instances the quantity of material operated upon has been too small to permit of the attainment of satisfactory results by methods in which the sources of error were not inconsiderable.

There is no doubt, however, that the different conclusions arrived at by many talented chemists with regard to the composition of gun-cotton, are to be mainly ascribed to the fact that the treatment of cotton-wool with nitric acid, or a mixture of nitric and sulphuric acids, has furnished, in the hands of different operators, products differing considerably in composition. That such is the case is clearly indicated by the statements made in several of the published researches with regard to the increase of weight sustained by the cotton upon treatment with acid. Thus Pélouze, in his first paper on the composition of pyroxylin, states that he found the increase of weight constantly comprised between 68 and 70 per cent. In his next publication he fixes the increase of weight at between 74 and 76 per cent., the theoretical increase, according to the formula which he fixed upon, being 74·9 per cent.; and Von Kirchhoff and Reuter obtained an increase of 76 per cent. Gladstone also found the increase of weight to be between 73 and 76 per cent. Porret and Teschemacher obtained an increase of only 54 per cent.; Teschemacher afterwards found the increase to be 69 per cent. Gregory and Schmidt and Hecker arrived at a similar result; while W. Crum, whose experiments were made with very carefully purified cotton, obtained an increase of 78 per cent. The increase of weight which, in other instances, the cotton must have sustained for the attainment of the analytical results quoted, must have been even more various: thus RANSOME'S results would indicate an increase of weight of only 65·4 per cent., while those of PÉLIGOT correspond to a gain of 94·4 per cent.

---

* The notation employed by the several experimenters is retained in this statement.

Other indications of differences in the characters of the products operated upon by different chemists are furnished by statements made with regard to the action of solvents upon them. Their solubility in mixtures of alcohol and ether evidently varied considerably; and in one instance of these earlier experiments (namely those of MM. MÉNARDE and DOMONTE in 1846), a description of gun-cotton soluble in ether and alcohol was described as obtained together with a proportion of an insoluble product. The analysis of the latter furnished results which correspond very closely to those demanded by the formula

$$C_{12}\left\{\begin{matrix} H_8 \\ 2NO_4 \end{matrix}\right\}O_{10}.$$

BÉCHAMP instituted some researches upon gun-cotton in 1852, in which he obtained, by the action of ammonia upon a soluble form of gun-cotton, a substance to which he assigned the formula

$$C_{24}H_{17}O_{17}, 4NO_5 \; (C_{24}H_{34}\Theta_{17}, 4N_2\Theta_5),$$

viewing it as pyroxylin from which one equivalent of nitric anhydride had been abstracted; he therefore considered that the formation of this substance confirmed PÉLOUZE'S view of the composition of gun-cotton.

It was believed by some chemists at about this period that pyroxylin was itself only slightly soluble in mixtures of alcohol and ether, but that these mixed solvents either modified its character, or separated it into two distinct explosive bodies, the one being soluble, and the other insoluble in the ether and alcohol. Others regarded the difference in solubility exhibited by gun-cotton, according to the manner in which it had been prepared, as ascribable to differences of molecular condition and not of composition.

But all the early investigators of this subject appear to have agreed in the opinion that the action of nitric acid, or the mixed acids, was completed in a few minutes, and that, however much the treatment with acids was protracted, no further change was effected.

GERHARDT, in his 'Traité de Chimie Organique' (1854), states that, as no gas is disengaged in the production of pyroxylin (a point upon which PÉLOUZE lays stress in his earlier papers), this substance may be affirmed to contain the elements of cellulose *plus* two or three proportions of the elements of nitric anhydride, and that it may be represented as cellulose in which two or three atoms of hydrogen are replaced by their equivalent of peroxide of nitrogen. This view of the composition of gun-cotton, which was first enunciated by CRUM, received very strong support from the interesting researches of HADOW, published in 1854. The experiments of this chemist furnished conclusive evidence of the possibility of producing four distinct varieties of pyroxylin, by submitting cotton-wool to the action of different mixtures of nitric and sulphuric acids. Moreover, by carefully determining the increase of weight sustained by the cotton upon immersion in acid mixtures of different composition, and also by applying a new process to the examination of the products, HADOW succeeded in establishing the composition of three of these substances.

By repeated immersion of pure cotton in a mixture of the strongest sulphuric and nitric acids, HADOW obtained an increase of 81·34 per cent., a number considerably higher than that obtained by previous experimenters, and nearly corresponding to the theoretical gain (83·3 per cent.) which cotton would sustain by its conversion into a product of the formula

$$\text{Ꞓ}_{18}H_{21}\Theta_{15}, 9N\Theta_2, \text{ or } \text{Ꞓ}_6\left\{\begin{matrix} H_7 \\ 3N\Theta_2 \end{matrix}\right\}\Theta_5, \text{ or } \text{Ꞓ}_{12}H_{14}\Theta_7, 3N_2\Theta_5 (C_{36}H_{21}O_{30}, 9NO_4, \text{HADOW}).$$

By determining, in the form of nitric acid, the oxide of nitrogen contained in the product, and reproducing the cotton from the latter by the action of potassic sulphhydrate, HADOW moreover obtained numerical results closely agreeing with those which should be furnished by trinitro-cellulose or trinitric cellulose, and therefore confirmatory of the conclusion which was based upon the weight of the product furnished by as complete a treatment as possible of the cellulose with the strongest nitric and sulphuric acids. Similarly, HADOW established the composition of two lower nitric-products, having respectively the formulæ

$$\text{Ꞓ}_{18}H_{22}\Theta_{15}, 8N\Theta_2 (C_{36}H_{22}O_{30}, 8NO_4)$$

and

$$\text{Ꞓ}_{18}H_{23}\Theta_{15}, 7N\Theta_2 (C_{36}H_{23}O_{30}, 7NO_4),$$

and differing from the highest compound in being soluble in mixtures of ether and alcohol.

Not long after HADOW'S researches were made known, BÉCHAMP published a continuation of his experiments with soluble gun-cotton. In this paper he adheres to the conclusion that PÉLOUZE'S formula for pyroxylin ($C_{24}H_{17}O_{17}, 5NO_5$) is correct, because he obtains, by the action of ammonia and potassa upon that substance, products the composition of which he represents by the formulæ

$$C_{24}H_{17}O_{17}, 4NO_5 \text{ and } C_{24}H_{17}O_{17}, 3NO_5.$$

REDTENBACHER, SCHRÖTTER, and SCHNEIDER, in a joint report prepared by them in 1863 on gun-cotton manufactured by Baron von LENK, adopted the view that the most explosive variety of gun-cotton was trinitro-cellulose, and quoted several satisfactory analytical results in proof of their assertion that gun-cotton prepared according to LENK'S directions was that substance in a nearly pure condition.

The composition of the most explosive gun-cotton was indeed very generally regarded as definitely established to be trinitro-cellulose, or trinitric cellulose, until the publication (in 1864) of the memoir of Pélouze and Maury, in which that view is combated, and a new formula,

$$C_{24}H_{18}O_{18},\ 5NO_5\ (C_{24}H_{36}\Theta_{18},\ 5N_2\Theta_5),$$

is assigned to that substance, which differs, by the elements of one equivalent of water, from Pélouze's second formula, adopted in 1847.

Some analytical results are referred to by Pélouze and Maury in support of their view of the composition of gun-cotton; but they base their new formula principally upon the increase of weight which they have found cotton to sustain by treatment with the mixed acids, and which they now fix at 78 per cent. (the numbers formerly arrived at by Pélouze being from 68 to 70 and from 74 to 76 per cent.). The theoretical increase of weight which *pure cellulose* should sustain upon complete conversion into a substance of the composition assigned to it by Pélouze and Maury is 77·78 per cent.; while, if gun-cotton were completely converted into trinitro-cellulose, it should gain in weight 83·3 per cent.

It would appear that these numbers are sufficiently far apart to preclude any uncertainty with regard to the correctness of a conclusion in favour of either formula, if based upon careful and sufficient experiments. Nevertheless, Pélouze and Maury state, on the one hand, that they base their somewhat complex formula upon the results of many experiments, variously instituted; while, on the other hand, the results arrived at by Hadow, which are not in any way referred to by Pélouze and Maury, and have never yet been called into question, appear to furnish very strong evidence in favour of the more simple formula.

Early in 1863, by desire of the Secretary of State for War, I entered upon a detailed investigation of the manufacture of gun-cotton, the composition of the material when produced upon an extensive scale, its behaviour under circumstances favourable to its change, and other subjects relating to the chemical history of this remarkable body.

The continuation of these investigations was afterwards entrusted to me by my colleagues, upon the appointment of a Government Committee on Gun-cotton.

The circumstance that the manufacture of the supplies required for artillery- and other experiments has been carried on under my direction, has enabled me to institute numerous experiments upon a considerable scale, in some of which the conditions of manufacture have been varied, while in others the quantity of product furnished has been carefully determined. By combining such experiments with a very extensive series of analytical and synthetical laboratory investigations, I have endeavoured to render both rigorous and exhaustive the examination into the uniformity of the process of manufacture of gun-cotton as perfected by Von Lenk, and into the composition of the product.

I.—MANUFACTURE OF GUN-COTTON.

The system of manufacture of gun-cotton which is the result of Von Lenk's persevering endeavours to perfect this material, does not, at first sight, present any important features of novelty, when compared with the methods of operation prescribed by SCHÖNBEIN, BÖTTGER, OTTO and others, and pursued upon an extensive scale, for a short time, at Messrs. HALL'S gunpowder works, and at Bouchet. Acids of the specific gravity prescribed by Von LENK and mixed in very similar proportions to those which he indicates, were employed; in some instances the cotton was submitted to a preliminary purification, as directed by him, and the product, after being washed in water, was also submitted to treatment with an alkaline bath, the mode only of carrying out this process of purification differing somewhat from that which Von LENK adopts. But the application, upon a manufacturing scale, of the system which has been pursued under LENK'S direction at the manufactory at Hirtenberg, brings to light several details of considerable value, the adoption of which unquestionably ensures the attainment of greater uniformity and purity of the product of manufacture than could be secured by the earlier modes of operation.

The important steps in Von LENK'S system of manufacture are briefly as follows:—

1. The carded cotton is spun into a loose yarn, varying in size and strength according to the applications it is to receive; and the yarn is made up into hanks of convenient size (weighing about three ounces).

2. The cotton is submitted to preliminary purification by boiling it for a few minutes in a solution of potassic carbonate, of specific gravity 1·02, separating the alkaline liquid by means of a centrifugal extractor, and washing the cotton thoroughly in water.

3. The cotton is perfectly dried by artificial heat, immediately before its treatment with acid.

4. The acid used for the production of the gun-cotton is prepared by mixing one part by weight of nitric acid, of specific gravity 1·52, with three parts of sulphuric acid of specific gravity 1·84. This mixture is allowed to become perfectly cold before use.

5. The dry cotton is immersed by small quantities (about six ounces, or two hanks, at one time) in a bath of the mixed acids, which is kept as cool as possible. When the cotton has become thoroughly saturated and has been moved about in the acids for a few minutes, it is removed from the bath to a ledge placed over it, where a portion of the acid absorbed is separated by gentle pressure; the hanks are then transferred to small covered stoneware vessels, in which they are preserved for forty-eight hours, the proportion of acid with which they are allowed to remain saturated for that period being 10·5 parts by weight to 1 of the original cotton. The vessels containing the gun-cotton and acid are kept as cool as possible by being surrounded with water.

6. The acid removed from the bath by each successive quantity of cotton immersed, is replaced by the addition of a corresponding quantity of the fresh mixture, before another quantity of cotton is treated.

7. After the lapse of forty-eight hours, the acid is separated from the gun-cotton as completely as possible by mechanical means (*i. e.* by means of the centrifugal extractors). The expressed acids are not employed again.

8. The hanks are then drenched with water, singly, as rapidly as possible; they are

afterwards washed by hand until no longer acid to the taste, and are afterwards placed in crates or perforated boxes and kept immersed in flowing water for about three weeks.

9. At the expiration of that time the water is separated mechanically from the gun-cotton, and the moist skeins are boiled for fifteen minutes in a solution of potassic carbonate of specific gravity 1·02. When the alkaline liquor has been expressed, the skeins are once more immersed in flowing water for a few days; the finished gun-cotton is then dried by exposure to air.

10. It is afterwards allowed to soak for about one hour in a cold solution of sodic silicate of specific gravity 1·072. The liquid is then expressed from the hanks in the usual manner; after which they are allowed to dry thoroughly, again washed for five or six hours in running water, and finally by hand. The thorough desiccation of the gun-cotton then completes its manufacture.

The employment of the cotton in the form of hanks of loosely spun yarn, instead of simply in the loose carded condition, considerably facilitates its conversion and purification. The proper impregnation of the cotton by the acids is more rapidly accomplished with the hanks; such manipulations as attend the separation of the main quantity of acid from the converted material, and its first rapid and complete immersion (while still saturated with the concentrated acids) into water, are much more readily carried out with the cotton in the spun form; and, again, the exposure of the latter to the full purifying effects of a current of water is much more simply and perfectly effected than if carded cotton be used, while the mechanical loss of wool and of gun-cotton, in the several operations of washing and expressing, is much reduced. I have perfectly satisfied myself of the advantages just pointed out, by operating upon considerable quantities of carded cotton-wool. In these experiments it was found impracticable, moreover, except by application of very powerful pressure, to reduce the proportion of acid which the wool retained after immersion (and which had to be left in contact with it, as prescribed) below that of fourteen parts to one of cotton, whereas with the yarn there is no difficulty in reducing the quantity, by moderate pressure, to ten parts, or even lower. The consumption of acid is therefore economized by using the cotton in a spun form.

The preparation of the mixture of nitric and sulphuric acids, as directed by Von LENK, involves no important point of novelty; the necessity of employing the mixture cold, and therefore of either submitting it to refrigeration before use, or preparing a stock of the mixture some time before it was required, was well known to the earlier operators*.

---

* An observation made by BÉCHAMP, in his papers on Pyroxylin, that the production of a soluble or an insoluble product was determined simply by conditions of temperature, when the conversion was effected by means of sulphuric acid and saltpetre, induced me to ascertain by experiment whether the solubility, in alcohol and ether, of the product obtained with the employment of the prescribed mixture of nitric and sulphuric acids, increased, if the temperature of the latter was raised to about 70° C. That temperature was fixed upon for the experiment as being the average of the freshly prepared mixture of nitric and sulphuric acids, usually employed for producing gun-cotton for photographic purposes, and which, in experiments instituted, furnished soluble gun-cotton yielding transparent collodion. The products obtained by the action of the warm mixture

In the treatment of the cotton with the mixed acids, the following precautions, viz. the immersion of uniform quantities of the perfectly dry cotton in the bath of acid, the adherence to a fixed proportion in weight between the cotton and the acid with which it is left in contact, and the regular replacement of the acids removed from the bath at each successive immersion of cotton, by a corresponding quantity of fresh mixture, combine to exert no unimportant influence upon the uniformity of the product. That such is the case has been established by manufacturing experiments. For example, on one occasion some hanks of cotton were immersed in the bath of acids without addition to the latter of the quantity of fresh acid proportionate to the amount removed in the previous operation of immersion. The resulting product, which was in all other respects treated as usual, exhibited a decided difference, both in its composition and its explosive powers, when compared with gun-cotton previously produced, strictly according to rule, in the same bath of acids.

As regards the period during which the cotton is allowed to remain immersed in the acids, the precise time fixed upon by LENK (forty-eight hours) appears to be arbitrary, but there is good reason for prolonging for several hours the contact between the acids and the product. That a few minutes' immersion of a small quantity of cotton may be sufficient to convert it into a highly explosive and even to a great extent into the most explosive product, is indisputable; but a considerable period elapses before the cotton, especially when it is spun and when at least 6 oz. are operated upon at one time, is converted, as *completely as possible* by one single treatment, into the most explosive product.

In operating upon small quantities of cotton, when the proportion of acids employed is always considerably in excess of that prescribed by Von LENK, an immersion of the cotton for two hours has been found to furnish results quite as perfect as those obtained by protracting the immersion for forty-eight hours. Even when the proportion of acid to cotton was reduced, in small experiments, as nearly as possible to that employed in a manufacturing operation, the results of twelve and twenty-four hours' immersion were quite equal to those produced by treatment for the full period; indeed, decided evidence was obtained that the very long-continued contact of gun-cotton with the acids gave rise to a slight loss, a small proportion of the product being eventually dissolved by the acids. But when the duration of the treatment of even small quantities of cotton (between three and four grammes) with a large excess of acid was limited to ten minutes, the conversion was comparatively very imperfect, and the products contained considerable proportions of soluble gun-cotton.

---

upon the cotton-wool exhibited no difference as regards its insolubility, from the ordinary products furnished by the cold mixture. Neither was insoluble gun-cotton rendered at all soluble by being submitted to treatment with the warm mixture. HADOW has shown that a more dilute mixture of acids which, when cold, furnishes an almost insoluble product, will, if employed at a temperature of 55° C., yield perfectly soluble gun-cotton, giving a fluid transparent collodion.

A careful examination of products of manufacture, prepared by continuing the contact of the acids with the gun-cotton for only one-half of the usual period (twenty-four hours), failed to indicate any difference between them and products obtained by the full period of immersion; on the other hand, a prolongation of the immersion to seventy-two hours did not furnish results more closely in accordance with theoretical demands than the ordinary treatment.

It was found, by experiments with several hundred pounds of spun cotton, that a considerable increase beyond the prescribed proportion of acid left in contact with the gun-cotton (eighteen or twenty parts instead of ten parts to one of cotton) furnished products which differed from those obtained by a strict adherence to LENK'S directions, only in containing somewhat smaller proportions of foreign matters than products in the manufacture of which ten parts of acid had been used.

The heat resulting from the chemical action of the nitric acid upon the cotton, and from the union of the acids with the liberated water, is considerable; it is therefore quite as important that the bath of acid in which repeated immersions are effected should be kept cool by being surrounded with cold water, as that the acid mixture should in the first instance be perfectly cold. Moreover, the precaution which Von LENK adopts (excepting in cold weather) of keeping the closed vessels, in which the gun-cotton remains for forty-eight hours in contact with the acids, surrounded by cold water, is also very essential; for otherwise the accumulation of heat by the contents of the vessel, in consequence of the gradual conversion of some portions of the cotton, after its removal from the bath, may occasionally become sufficiently considerable to establish a destructive action of the acids upon the gun-cotton.

There can be no question as regards the necessity of employing some method, such as that adopted by Von LENK, for rendering as sudden and complete as possible the first immersion into water of the gun-cotton which is still saturated with acids (though these have been separated from it as far as possible by means of a centrifugal extractor); for if the hanks are simply thrown or dipped into water, the heat generated by the gradual penetration of the latter into the compact mass of gun-cotton, saturated with concentrated acids, suffices to establish in some parts a destructive action of the latter upon the gun-cotton, which is rendered evident by the disengagement of nitrous vapours, and which, though it is very speedily checked, as the acid becomes largely diluted by water, may give rise to the production of small quantities of substances of comparatively unstable character, not removed from the gun-cotton by the subsequent purification. The most effectual plan of rapidly diluting the acid in the gun-cotton is to throw the skeins just removed from the extractor singly *into* a cascade of water, whereby the instantaneous penetration of the mass of cotton by a large body of water is accomplished with ease and certainty.

The subsequent continuous immersion of the gun-cotton for at least three weeks in a stream of water, as directed by Von LENK, is unnecessarily long, as the gun-cotton is afterwards still subjected to treatment with an alkaline water, and to a final washing.

In the manufacturing operations carried on at Waltham Abbey, where only a very slow stream of water was available for the purposes of purification, the period for which the gun-cotton was allowed to remain in the water, after the preliminary washing in the cascade, was in some instances forty-eight hours, in others from ten to fourteen days. There is no question that the latter period was excessive, especially with the improved methods there adopted of exposing the gun-cotton to the purifying action of the water. Indeed there can be no doubt that this first washing is of minor importance, as effecting the ultimate purity of the product, compared to the treatment with alkaline liquid which it receives, and which, according to Von Lenk's directions, consists in boiling the gun-cotton for about fifteen minutes in a solution of potassic carbonate of specific gravity 1·02. The gun-cotton, manufactured nearly three years ago at Waltham Abbey, which was submitted to a first washing of only forty-eight hours, but was washed for a fortnight after treatment with alkali, has proved in every respect equal in permanence to products of more recent manufacture which have been submitted to the long-continued first washing. The curtailment of this washing operation, if compatible with perfect security, would be important, not only on account of the time saved in the manufacture, but also because, if the gun-cotton remains immersed in spring- or river-water in localities where light cannot be perfectly excluded, vegetable growth is speedily established upon it, and the perfect separation from it of extraneous organic matter becomes afterwards a very difficult and time-consuming operation. But, although the perfect permanence, for a period of nearly three years, coupled with very great power of resisting the destructive effects of heat and light, possessed by products in the manufacture of which the long-continued washing was postponed until after the alkaline treatment, warrant the belief that this method of operating secures the proper purification of the product, I have obtained indications, in other manufacturing operations, that a very considerable curtailment of the *total* purification, by washing, which the gun-cotton receives, in addition to the treatment with alkali, somewhat diminishes its power of resisting destructive influences. The omission of the treatment with an alkaline bath affects to a much more decided extent the permanence of the gun-cotton; indeed it is doubtful whether, even if the washing were protracted considerably beyond the full time prescribed by Von Lenk, the gun-cutton would be as perfectly purified as it is by being washed only for a short time and then boiled for a few minutes in an alkaline solution.

If it were possible to operate on a large scale upon *pure* cotton fibre, the functions of the alkaline bath, used as a purifying agent, would simply be to neutralize and remove from the pyroxylin any traces of acid not separated by washing. But as it is only possible to submit cotton to very partial purification in manufacturing operations, its treatment with the acid must partially, or completely, convert into oxidized products the small quantities of resinous and other foreign substances still retained by the tubular fibre. An examination of many specimens of gun-cotton has shown that at any rate some of these products, which may be comparatively unstable in character, are much less readily removeable from the gun-cotton by simple washing than the acids with which it is impregnated; the solvent action of the alkaline bath upon these is therefore very probably one of its most important functions.

As the difficulties attending the perfect removal of the acid with which gun-cotton remains impregnated after its conversion are mainly attributable to the tubular structure of the cotton fibre, and to the circumstance that the latter contracts considerably upon conversion into pyroxylin, the complete purification of the material is very greatly facilitated by reducing the gun-cotton fibre to a fine state of division, similar to that of the pulp used in paper manufacture, in which form it appears likely that gun-cotton will receive advantageous application. By submission to the "pulping" process, the gun-cotton is divided into very minute fragments, and is at the same time violently agitated for some considerable time with a very large volume of water (rendered slightly alkaline if necessary), which is afterwards thoroughly expressed when the pulp is converted into cylinders or other forms; so that a more searching supplementary process of purification can scarcely be conceived than this disintegration of the gun-cotton.

The treatment of the purified gun-cotton with a solution of soluble glass, which constituted a prominent feature in Von LENK'S system of manufacture when the latter first became known in this country, has been shown by SCHRÖTTER, REDTENBACHER and SCHNEIDER, by myself, and more recently by PÉLOUZE and MAURY, to possess no important merits. If gun-cotton, which has been thus treated, has ever been found to resist the destructive effects of exposure to elevated temperatures longer than equally pure gun-cotton to which no silicate has been applied, this must be ascribed to the introduction between the fibres of the gun-cotton of small quantities of substances which would exert a neutralizing action upon minute traces of acid not removed from the gun-cotton by the purifying process, or of any acid liberated or generated by the influence of heat.

Some hydrated calcic and magnesian silicates, produced by the decomposition of the alkaline silicate when the gun-cotton is washed in spring-water after its impregnation with soluble glass and desiccation, and possibly some small proportion of alkaline carbonate and silicates, which have escaped removal in the final washing, may exist in the gun-cotton submitted to the silicating treatment, and may act to some extent as protectives, in the manner pointed out. The examination of Austrian and other specimens of gun-cotton which had been submitted to the silicating process showed that some or all of those substances existed in these in small and variable quantities. But other specimens, such as the general products of manufacture at Waltham Abbey, to which no soluble glass had been applied, but which had remained for many days immersed in somewhat hard water, were found to contain calcic and magnesian carbonates, in proportions sufficient to exert quite as great a protective action as the substances deposited in the gun-cotton by submission to Von LENK'S "silicating" treatment. In the account which I hope before long to give of the action of light and heat upon gun-cotton, it will be shown that the impregnation of the material with small proportions of alkaline or earthy carbonates is likely to prove a very important protective measure; but it need hardly be stated that there are much more simple and certain methods of distributing such substances uniformly through a mass of gun-cotton than the treatment with soluble glass and subsequent washing. Thus, considerable quantities of gun-cotton have been uniformly impregnated at Waltham Abbey, for experimental purposes, with sodic carbonate (in the proportions of 0·5 and 1 per cent.), simply by soaking the finished gun-cotton in solutions of that substance, of definite strength, expressing the excess of liquid in the usual manner, and then drying the skeins.

It will be seen from the foregoing observations on the Austrian system of manufacture, which are almost exclusively based upon the results of experience in the manufacture of considerable quantities of the material during the last three years, that General Von Lenk has not actually initiated any new principle as applied to the production of gun-cotton, but that he has, by long experience and persevering investigation of the subject, so perfected the process of converting cotton-wool into the most explosive form of gun-cotton and of purifying the product, as to render a simple attention to clear and definite regulations alone necessary to ensure the manufacture of a very uniform material, which is unquestionably much more perfect in its nature than the products obtained in the earlier days of the history of gun-cotton. Such being the case, too much stress cannot be laid upon the fact that deviations from the prescribed process, which at first sight may appear very trivial (such as a slight reduction of the strength of the acids, the neglect of proper cooling arrangements, &c.), are certain to lead to variations in the products of manufacture affecting their explosive characters, or their permanence, or both. In discussing the composition of gun-cotton manufactured by Lenk's system, I shall have to refer to several samples of the material, produced at Hirtenberg and at Stowmarket, which differed widely in their composition and properties from the normal product of manufacture. I have obtained abundant and most conclusive proof that these exceptional variations are solely ascribable to the neglect of a uniformly strict adherence to the prescribed process of converting the cotton; and I am strongly of opinion that their occurrence has almost always been due to the employment of nitric acid which exhibited a fictitious specific gravity, from the presence either of considerable quantities of peroxide of nitrogen, or of some other impurity (such as sulphuric acid). A searching examination of the ordinary products of manufacture obtained at Waltham Abbey, where the quality of the nitric acid employed received uniformly strict attention, has shown that, without any exception, the variations in their composition were embraced within very narrow limits.

II.—COMPOSITION OF GUN-COTTON.

The researches instituted by me into the composition of gun-cotton have been conducted partly with ordinary products of manufacture, obtained from Waltham Abbey and from the gun-cotton factories at Hirtenberg and Stowmarket, and partly with products prepared in the laboratory with purified and very finely carded cotton-wool. The latter was more particularly employed in experiments instituted for the purpose of accurately ascertaining the maximum increase of weight which cotton-wool will sustain by treatment with mixed nitric and sulphuric acids, while the products of ordinary manufacture have been employed in the analytical experiments.

The loosely spun cotton-wool from which these products are obtained varies somewhat in purity, even after the preliminary treatment with alkali and washing which it undergoes previous to conversion. The material, as supplied to Waltham Abbey by the cotton-spinners, always contains seed fragments, which are only very partially removed by the purifying process, but are in most instances completely dissolved or mechanically removed during the processes of conversion and purification. The purified cotton is always considerably inferior in whiteness to the converted material. The loss sustained by the cotton in the treatment with potassic carbonate and subsequent washing, ranged between 5 and 10 per cent. An average sample of the cotton used was submitted to analysis after having been purified in the usual manner. It contained 0·044 per cent. of ash, and the following percentage proportions of carbon and hydrogen:—

	Found.	Cellulose.
Carbon	44·26	44·44
Hydrogen	6·05	6·17
Oxygen	49·69	49·39

Hygroscopic moisture existing in gun cotton.—The amount of water absorbed and retained by gun-cotton under normal atmospheric conditions is very uniform; the average proportion is 2 per cent.; and although gun-cotton will gradually absorb as much as 6 per cent. of water if exposed for a sufficient period to a very moist confined atmosphere, the proportion which it retains upon re-exposure to open air rarely exceeds 2 per cent. This amount is rapidly reabsorbed by gun-cotton, after perfect desiccation *in vacuo* over sulphuric acid.

Mineral constituents of gun-cotton.—The proportion of mineral constituents (or ash) in gun-cotton has been carefully determined in a large number of products of manufacture. The mode of operation consisted in thoroughly moistening the dried and weighed gun-cotton (about 4 grms.) in distilled water, and then projecting it, in small fragments, into a deep platinum vessel of known weight heated to low redness. The decomposition of the gun-cotton under these conditions is so gradual, that there is no risk of the mechanical dispersion of any of the ash. After the combustion of the gun-cotton was completed, the temperature of the vessel was raised sufficiently to burn off minute quantities of carbon which had separated during the slow combustion. The variation in the amount of ash obtained from different samples of gun-cotton manufactured at the same works was but slight; 1 per cent. was the average proportion existing in gun-cotton manufactured at Waltham Abbey. A few samples examined contained a somewhat higher proportion, and some specimens, obtained from Hirtenberg, furnished an average proportion of nearly 2 per cent. An analysis of the ash in these instances indicated that the gun-cotton had been submitted to the "silicating" treatment adopted by LENK. The ash furnished by gun-cotton not thus treated consisted principally of calcic carbonate and other impurities (sand, clay, &c.) deposited between the fibres during the immersion of the gun-cotton in the stream.

Proportion of the gun-cotton dissolved by ether and alcohol.—Hadow found that the highest product which he obtained by the action of nitric and sulphuric acids upon cotton-wool, and the composition of which agreed closely with the requirements of the formula

$$C_6 H_7 O_5, 3N O_2, \text{ or } C_{12} H_{14} O_7, 3N_2 O_5,$$

was perfectly insoluble in any mixture of ether and alcohol; but that the lower products, obtained by the action of acid-mixtures containing larger proportions of water, were more or less readily soluble in ether, used alone or in admixture with alcohol. Although, in operating upon small quantities of carefully purified cotton-wool with a considerable proportion of the acid-mixture, the most explosive gun-cotton can be obtained without difficulty in an almost pure condition (containing only mere traces of matters extractable by ether and alcohol) by one single treatment of the cotton, it could scarcely be expected that, in a manufacturing operation, more than a close approximation to this result could be arrived at, when it is remembered that a considerable time elapses before the action of the acids upon the entire quantity of cotton with which they remain in contact is completed, and that, during the period occupied by the conversion of the last portions of cotton, the acid in contact with the fibres becomes diluted by the water eliminated in the reaction, and does not therefore retain to the last the composition required for the production of the most explosive gun-cotton. But it is remarkable how very close and uniform an approximation to complete conversion of the cotton into the most explosive product is attained by properly carrying out Von Lenk's instructions.

A very large number of the ordinary products from Waltham Abbey have been carefully examined, with the view of determining the average percentage of soluble matter in the gun-cotton. In the first experiments, the weighed gun-cotton (between 2 and 3 grms.) was packed closely into a tube of about 12 millims. diameter and constricted to a fine opening at the lower extremity. The mixture of ether and alcohol which was poured on to the gun-cotton in the tube filtered through it very slowly. When the filtrate furnished what appeared an unimportant quantity of residue, the cotton in the tube was dried and its loss in weight determined. Upon examining the samples of gun-cotton thus treated, they were found, however, still to contain matter soluble in the ethereal mixture, and it was evident that, by this mode of treatment, either the soluble matter could not be separated from the insoluble fibre, or only the most readily soluble portions (which furnish a tolerably limpid solution) were carried through by the liquid; while those less easily dissolved, and which were, indeed, more glutenized than actually dissolved, remained in the tube. A different mode of operating was therefore resorted to. From 8 to 10 grammes of the gun-cotton were digested in a stoppered bottle for from thirty to fifty hours (according to the apparent extent of action of the solvent) with from 60 to 100 centimetres of the ethereal mixture. At the expiration of this digestion the contents of the bottle were agitated slightly, a small portion of the gun-cotton was removed and placed as a plug in the apex of a funnel, through which the liquid was filtered into an evaporating dish. The gun-cotton was then transferred to a suitable instrument, placed over the funnel, and the liquid expressed; it was afterwards returned to the bottle, in which it was digested for a second (and sometimes a third) similar period with fresh solvent, the washings of the funnel, &c. being returned to the bottle. When the gun-cotton had been two or three times digested and expressed, it was washed upon the funnel. The liquid thus obtained never contained more than two or three minute fibres of the gun-cotton; it was generally of a very pale straw colour, and slightly opalescent. When evaporated nearly to dryness it became gelatinous, and gradually dried to a yellowish substance of somewhat resinous appearance.

The following results were obtained in this manner, a different sample being operated upon in each instance:—

	Description of gun-cotton.	Percentage of soluble matter.
Made in 1863.	Coarse yarn	1·70
,, ,,	Fine yarn	1·33
,, ,,	Coarse yarn	1·91
,, ,,	Fine yarn	1·53
Made in 1864.	Coarse yarn	2·00
,, ,,	,,	2·60
,, ,,	,,	1·81
,, ,,	,,	2·12
,, ,,	,,	2·31
,, ,,	,,	1·99
,, ,,	Fine yarn	2·35
,, ,,	,,	2·25
,, ,,	,,	1·83
,, ,,	,,	2·34
,, ,,	Coarse yarn	1·62
Made in 1865.	,,	2·30
,, ,,	,,	2·22
,, ,,	,,	1·93
,, ,,	,,	2·21
,, ,,	,,	2·22

Mean average of matter soluble in alcohol and ether, from results of examination of twenty samples of ordinary products of manufacture at Waltham Abbey	2·03 per cent.
Extreme results obtained	=1·3 and 2·6 ,,
Soluble matter in gun-cotton prepared by twenty-four hours' treatment with acids	1·99 ,,

Soluble matter in gun-cotton prepared by seventy-two hours' treatment with acids	2·34 per cent.
Soluble matter in gun-cotton submitted to a second treatment for forty-eight hours with the usual acids	2·40 „

Somewhat higher results were obtained by submitting the material to long-continued agitation with ether and alcohol, and repeating the digestion and agitation several times with fresh solvent; but the gun-cotton became so disintegrated by this treatment, that it was very difficult to filter the liquid so as to obtain it free from fibres; it was moreover found that a considerable proportion of the finely-divided mineral matter attached to the gun-cotton became suspended in the liquid and could not be separated. Repeated experiments showed that, after the second digestion of Waltham Abbey gun-cotton, there were only very small quantities of soluble matter extracted, which it appeared almost impossible to remove perfectly by this mode of treatment; the above numbers may therefore be accepted with confidence, as representing a close approximation to the average proportion of matter soluble in ether and alcohol contained in the normal products of gun-cotton manufactured according to Von LENK's prescription.

I was led to submit the products of the Waltham Abbey manufacture to a particularly searching examination, with reference to the proportion of matters extractable by ether and alcohol, because an examination of several of the samples of gun-cotton obtained from the Stowmarket and Hirtenberg factories, furnished results differing considerably from each other and from those obtained with the first Waltham Abbey samples examined.

The following are the proportions of soluble matter found in gun-cotton manufactured in Stowmarket in 1864:—

Specimen.	Per cent.	Specimen.	Per cent.
1	4·0	9	3·68
2	3·2	10	4·24
3	3·41	11	3·34
4	4·10	12	4·65
5	12·55	13	8·50
6	2·85	14	5·10
7	4·10	15	4·07
8	4·35		

The variations exhibited by these numbers, and the comparatively large proportion of soluble matter existing in some of the samples, must unquestionably be ascribed to some irregularity in the treatment with acids, as practised at Stowmarket, due perhaps to exceptional circumstances existing at the time these samples of gun-cotton were manufactured; the examination of several products of more recent date obtained from Stowmarket, has furnished much more uniform results, the majority of which correspond nearly to those obtained with the Waltham Abbey gun-cotton.

Several of the specimens of gun-cotton obtained from Hirtenberg were also found to contain comparatively large quantities of soluble matter, and the proportions in two or three samples were very high. The following are the results obtained with those which differed from the Waltham Abbey products:—

Specimen	Per cent.
1	8·60
2	7·44
3	14·10
4	5·02
5	4·50
6	14·21
7	3·02
8	3·66
9	5·32

Another Austrian specimen* contained so high a proportion soluble in alcohol and ether that the yarn was entirely broken up by a brief digestion with the solvent; a large quantity of nearly transparent solution was separated from it, but the proportion of gun-cotton remaining insoluble could not be determined with any accuracy. A few other specimens of Hirtenberg gun-cotton corresponded closely to the Waltham Abbey products, as regards the proportion of soluble matter they contained.

The character of the soluble matter extracted from the Waltham Abbey products by ether and alcohol was very uniform.

The dry extracted matter, when digested with hot alcohol alone, dissolved to a very considerable extent, and a light yellow solution was obtained, which, on evaporation, furnished a yellow amorphous residue, almost entirely soluble in ammonia or sodic carbonate; the neutral liquids furnishing precipitates with lead- and silver-solutions. When the substance was heated with potassic hydrate, ammonia was evolved. When gradually exposed to heat on platinum or bibulous paper, it first fused and then deflagrated. The portion insoluble in alcohol dissolved in the ethereal mixture, the solution furnishing on evaporation a semiopake film, which contracted and split up into small horny particles when quite dry. The extracts from Stowmarket and Hirtenberg gun-cotton contained the same product soluble in alcohol alone, and generally in about the same proportion; but in most of those instances in which the specimen had furnished a considerable proportion of soluble matter, the part insoluble in alcohol yielded by solution in ether and alcohol, a liquid which approached in its character to photographic collodion; the film left by its evaporation being more or less tough, and nearly transparent. In two instances very good photographs were obtained with the collodion extracted from specimens of Austrian gun-cotton.

---

* This specimen, when I received it, was in distilled water, in which it had been preserved for twelve months. It need hardly be stated that the great solubility of the gun-cotton could not be ascribed to its having been thus preserved. The water containing it was perfectly neutral, and the gun-cotton exhibited no signs of having undergone change since its manufacture. A sample of Waltham Abbey gun-cotton, in which the soluble matter had been determined, was placed by me in distilled water at the time that the specimen above referred to was received. It has since been examined, having been in the water fifteen months, and was found perfectly unchanged.

The proportions of matter soluble in alcohol alone, and in the ethereal mixture, were successively determined in a few samples of gun-cotton, and furnished the following results:—

Description of gun-cotton.	Alcoholic extract. Per cent.	Ethereal extract. Per cent.		Total soluble matter.	Result obtained by direct extraction with ether and alcohol. Per cent.
Waltham Abbey, 1863 . .	0·75	1·31	=	2·06	1·91
,, 1864 . .	0·72	1·35	=	2·07	1·93
,, ,, . .	0·95	1·48	=	2·43	2·21
,, ,, . .	0·90	1·42	=	2·32	2·60
Stowmarket . . ,, . .	0·78	1·18	=	2·96	3·00
,, exceptional . .	0·95	11·78	=	12·73	12·55

The foregoing results show that, in the general products of manufacture obtained by properly following Von Lenk's instructions with regard to the conversion of the cotton, the proportion extracted by alcohol alone is somewhat below 1 per cent., and consists of nitrogenized matter, of acid character, which has evidently been produced by the action of nitric acid upon the resinous or other foreign substances contained in the cotton at the time of its conversion. The portion soluble in ether and alcohol, but insoluble in spirit, varies in amount between 1 and 2 per cent., and consists of the very small proportion of gun-cotton which has escaped conversion into the most explosive product. The occurrence, in a few quite exceptional instances, of comparatively large proportions of soluble gun-cotton, of the kind produced by the action of a warm somewhat dilute acid mixture upon cotton, affords important evidence of the necessity for adhering strictly to the mode of treatment, and the precautions, which considerable experience and a careful examination of products have proved to be indispensable to the attainment of uniform results in the manufacture of gun-cotton.

With regard to the matter soluble in ether and alcohol found to exist in gun-cotton, the following observations possess some interest, as bearing upon the cause of its production in the manufacture of the substance.

1. The mean proportion of soluble matter furnished by the very concordant results of examination of gun-cotton manufactured at Waltham Abbey in 1863, in the preparation of which the acids, left in contact with the gun-cotton, were in the proportion of 18 parts by weight to 1 of cotton, is 1·62 per cent.; while the mean proportion furnished by the results of examination of sixteen samples of Waltham Abbey products, in the manufacture of which only 10 parts of the acids were left in contact with the gun-cotton, is 2·13 per cent. All the results obtained with the first gun-cotton were below 2 per cent., while out of sixteen results, obtained with the last, eleven were above 2 per cent. Here we have a decided indication that the prolonged contact with acid has some influence upon the composition of the product; the employment of the higher proportion of acid furnished results more nearly approaching perfection than those when the gun-cotton was left in contact with a smaller proportion of the acid mixture. As far as can

be judged at present, however, from the general properties of the products, the difference observed when the larger or the smaller proportion of acid is used, is not of sufficient importance to render necessary the consumption of the larger quantity of acid in the manufacture.

2. The following experiment was instituted with a portion of one of the specimens of gun-cotton from Stowmarket, which had been found to contain 11·5 per cent. of matter soluble in ether and alcohol (after removal of the portion soluble in alcohol only). The gun-cotton, having been perfectly dried and carefully weighed, was digested for three hours with mixed nitric and sulphuric acids, of the kind always employed. It was afterwards submitted to long-continued washing with distilled water; precautions being taken to prevent mechanical loss. The dry gun-cotton was found to have increased in weight 0·3 per cent. But the original gun-cotton contained 1·71 per cent. of mineral matter, while, after having been digested with acids and washed, it furnished only 1·01 per cent. of ash. The difference between these numbers had therefore to be added to the increase in weight which the gun-cotton sustained by this second treatment with acids, which consequently amounted to 1 per cent. The substance now no longer contained any appreciable amount of soluble matter. Assuming that the soluble gun-cotton originally existing in the sample was either one of those whose composition has been determined by **Hadow**,

$$(\mathrm{C}_{18}\,\mathrm{H}_{22}\,\mathrm{O}_{15},\ 8\mathrm{N}\,\mathrm{O}_2,\quad \text{or}\quad \mathrm{C}_{18}\,\mathrm{H}_{23}\,\mathrm{O}_{15},\ 7\mathrm{N}\,\mathrm{O}_2),$$

the increase sustained by the imperfect sample, if completely converted into the most explosive and insoluble product, should have amounted in the one instance to 0·61 per cent., and in the other to 1·29 per cent. Considering that neither of these substances would be likely to exist alone in the imperfectly converted material, the actual increase of 1 per cent., sustained by the gun-cotton, must be regarded as a close approximation to the theoretical proportion of imperfectly converted gun-cotton, and proves decisively that, on the one hand, the treatment of the cotton with the acids had not in the first instance been quite perfect, while on the other a further digestion of imperfectly converted gun-cotton with acids will convert soluble gun-cotton which it contains, into the most explosive or insoluble variety.

Determination of the carbon, hydrogen, and nitrogen contained in gun-cotton.—The difficulties which attend the application of the ordinary analytical methods to determining the composition of so highly explosive a substance as pyroxylin, need scarcely be dwelt upon. Several special methods of proceeding have been pointed out by different experimenters; and others have been elaborated in the course of these researches; but even the most simple and perfect require great care and some experience in their employment, for the attainment of trustworthy results. The following is a brief account of the most successful methods tried for determining the carbon, hydrogen, and nitrogen, and of the results which each has furnished.

In the majority of instances the specimens of gun-cotton analyzed were ordinary products of manufacture. The material operated upon was always purified as far as possible, by repeated digestion and washing, from matters soluble in ether and alcohol; and, in calculating the results, allowance was made for the mineral constituents of the gun-cotton operated upon.

Carbon determinations. Method I.—The gun-cotton yarn was cut into small pieces, dried, and the fragments introduced singly into a very long combustion-tube, each portion being separated from the next by about 5 centimetres of oxide of copper. When the tube had received the entire quantity to be burned, about 15 centimetres of the anterior portion were filled with oxide of copper, and the remainder (about 20 centimetres) with porous fragments of reduced copper. The potassa-apparatus, used for absorbing carbonic acid, had a small chloride-of-calcium tube attached to it, which was weighed together with the apparatus, before and after the combustion. Although the greatest care was taken to proceed as slowly as possible with the heating of those portions of the tube containing the gun-cotton, the successful completion of the operation was a matter of great uncertainty, as the explosive combustion of some small portion of the gun-cotton would very frequently throw the surrounding oxide of copper forward, thus closing the necessary passage in the front part of the tube. This method was therefore abandoned after about two dozen experiments had been made, of which only four were brought to a satisfactory termination. The results of these were as follows:—

	Substance employed.	Carbon found.	
I.	0·2219 grm.	23·71 per cent.	Mean 24·02 per cent.
II.	0·3204 „	24·00 „	
III.	0·3790 „	24·26 „	
IV.	0·1996 „	24·12 „	

Method II.—The weighed substance was saturated with distilled water, and the latter removed as far as possible by pressure. The moist yarn was then cut into eight or ten pieces and introduced separately into one end of a long combustion-tube open at both extremities, and divided in the centre by a plug of asbestos. The shorter portion of the tube contained only the fragments of gun-cotton placed at distances of about 12 millimetres from each other; the longer portion was previously filled with long layers of oxide of copper, oxidized copper turnings, and porous reduced copper. This part of the tube was connected with a desiccating apparatus, to which were attached the potassa-bulbs with the small weighed chloride-of-calcium tube, fixed on to the outer limb. The extremity of that part of the combustion-tube which contained the gun-cotton was connected with an arrangement for passing an easily regulated current of pure dry air through the apparatus. The two portions of the tube were separated in the furnace by a screen. When the front part of the tube had been raised to a full red heat (at which it was maintained throughout the operation), the pieces of gun-cotton were consecutively made to undergo slow combustion, the portion nearest the asbestos plug being first heated, and the resulting gases and aqueous vapours being carried forward by the slow current of air continuously passed through the apparatus. This passage of air served to oxidize minute portions of carbon separated from the gun-cotton, when the whole tube was raised to a red heat at the close of the operation. The proportion of reduced copper employed was so regulated, that a considerable quantity remained unoxidized at the conclusion of the experiment. Great care was required in the application of heat to the parts of the tube containing the moist gun-cotton, there being otherwise considerable risk of its fracture by the water expelled from the heated substance.

The following are the results of eight carbon determinations made by this method in different specimens of gun-cotton manufactured in 1863. The quantities of material operated upon ranged from 0·2634 grm. to 0·4115 grm.

24·29 per cent.	24·35 per cent.	Mean=24·42 per cent.
24·58 „	24·59 „	
24·66 „	24·11 „	
24·52 „	24·18 „	

Method III.—A weighed quantity of gun-cotton, moistened as in the preceding experiments, was placed in a capacious strong Bohemian glass tube, sealed at one end; a small quantity of oxide of copper was introduced into the tube just in front of the gun-cotton. The other extremity of the tube was now constricted, and was sealed when the air in the tube had been exhausted. Heat was then carefully applied to the sealed tube until the gun-cotton had undergone slow combustion, and the oxide of copper was afterwards shaken to that part of the tube where a minute carbonaceous deposit had been left by the gun-cotton. The tube was placed in a gas-furnace and connected at one end with an apparatus for delivering pure air and oxygen, and at the other with a long combustion-tube, in a separate furnace, containing layers of oxide of copper and porous reduced copper, to which were attached a large chloride-of-calcium tube and the potassa-apparatus. The two Bohemian tubes were connected by a narrow india-rubber tube, about 12 centimetres long, fitted with a screw clamp, so that communication between the tubes could be cut off or gradually increased. The long tube having been raised to a red heat, the point of the sealed tube which was enclosed in the caoutchouc connexion was broken, and the confined gases were allowed to pass gradually over the heated oxide of copper and metal. When no further escape of gas from the tube took place, the other extremity, connected with the apparatus for delivering air, was broken, and the whole of the products of decomposition of the gun-cotton were gradually conveyed into the heated tube. Pure oxygen was finally passed through the apparatus, and the tube in which the gun-cotton had been burned was heated to redness.

The gun-cotton for these experiments was taken from various products of Waltham Abbey manufacture obtained in 1863 and 1864; the quantity employed varied between 0·2257 grm. and 0·39 grm. The following proportions of carbon were obtained:—

23·85 per cent.	24·06 per cent.	Mean 24·15 per cent.
23·90 ,,	24·57 ,,	
23·91 ,,	24·12 ,,	
24·26 ,,	24·60 ,,	
24·15 ,,		

Method IV.—The gun-cotton was reduced, by cutting, to an extremely fine state of division, and mixed when dry as intimately as possible with a very large proportion of chromate of lead, in the first few experiments, and of finely-divided oxide of copper in the remainder. Long layers of oxide of copper and porous reduced copper were employed as usual, and at the close of the combustion a current of pure oxygen, and finally pure air, was passed through the tube. With care and some experience, the combustion of the substance was brought perfectly under control by this comparatively simple method of proceeding; in a few instances, however, the operation was terminated prematurely by the stopping up of the tube, in consequence of the explosive combustion of a small accumulation of the finely-divided gun-cotton.

The following are the results obtained in carbon determinations with different specimens by this method. (The quantity of substance varied between 0·2263 grm. and 0·4839 grm.)

Coarse yarn, made in 1863.

Carbon found.

24·88 per cent.	24·36 per cent.
24·04 ,,	24·67 ,,

Coarse yarn, made in 1864.

Carbon found.

24·67 per cent.	24·37 per cent.
24·64 ,,	24·52 ,,
24·48 ,,	24·54 ,,
24·66 ,,	24·70 ,,

Medium yarn, made in 1864.

Carbon found.

24·54 per cent.	24·46 per cent.
24·69 ,,	24·70 ,,
24·87 ,,	24·61 ,,
24·76 ,,	24·78 ,,

Fine yarn, made in 1864.

Carbon found.

24·34 per cent.	24·39 per cent.
24·39 ,,	24·66 ,,
24·21 ,,	24·23 ,,
24·31 ,,	24·75 ,,

Mean result of 28 determinations=24·57 per cent.

The several mean results arrived at by the four different methods employed for determining the carbon in gun-cotton, manufactured by Von Lenk's process, are 24·02, 24·42, 24·15, and 24·57; the mean of 49 determinations is therefore 24·29. But the results, upon the accuracy of which the most perfect reliance is to be placed, are unquestionably those furnished by the fourth method, which ranged between 24·04 and 24·88 per cent., the mean being 24·57 per cent.

Determination of Hydrogen.—The hydrogen was determined at the same time as the carbon, by the method of operating last described. The results of all the combustions (eight in number), conducted with different samples of gun-cotton yarn, were so remarkably uniform, that they were regarded as furnishing ample numerical data, with respect to this constituent element. The following were the proportions of hydrogen found:—

2·41 per cent.	2·56 per cent.	Mean 2·46 per cent.
2·46 "	2·44 "	
2·40 "	2·47 "	
2·55 "	2·44 "	

Determination of Nitrogen.—The method of DUMAS was employed for determining, by volume, the proportion of nitrogen contained in gun-cotton. A rather wide combustion-tube, about 82 centimetres long, was drawn out at one end so as to admit of being connected with a carbonic acid apparatus provided with a regulating tap; and was fitted at the other end with the usual form of delivery tube. 5 centimetres of the tube were first filled with coarse porous fragments of oxide of copper, a layer of 3 centimetres of fine oxide of copper followed, and then the very finely cut gun-cotton, mixed with a large proportion of oxide of copper; the mixture occupying about 25 centimetres of the tube. The next 22 centimetres were filled partly with coarse porous oxide of copper, and partly with finely powdered oxide; a layer of 20 centimetres of reduced copper followed, and finally, the tube was plugged with coarse porous oxide, occupying a length of about 5 centimetres. The combustion was conducted very slowly, with the usual precautions, pure carbonic acid being passed through the apparatus for the requisite period before commencing, and at the conclusion. The gas collected was found, in one instance only, to contain traces of nitric oxide, and this determination was consequently rejected. The quantity of substance operated upon varied between 0·3006 grm. and 0·415 grm. The following are the percentage proportions of nitrogen calculated from the corrected volumes of gas observed:—

Description of gun-cotton.	Nitrogen found.
Coarse yarn, made in 1863 . . .	13·36 per cent.
	13·79 "
Fine yarn, made in 1864 . . .	13·44 "
	13·71 "
	13·58 "
	14·30 "
Medium yarn, made in 1864 .	14·60 "
	14·26 "
	13·59 "
Coarse yarn, made in 1864 . . .	13·60 per cent.
	13·68 "
	13·63 "
	13·79 "
	13·78 "
	14·03 "
	14·20 "
Medium yarn, made in 1864 .	13·97 "
	13·73 "

The results of these eighteen analyses of various products from Waltham Abbey ranged, therefore, between 13·36 and 14·60, and give the number 13·83 as the mean percentage of nitrogen contained in the material.

Deductions from the Analytical Results.—The formula adopted by Hadow, as representing the most explosive product of the action of mixed nitric and sulphuric acids upon cellulose,—which is the same as that first suggested for gun-cotton by W. Crum, afterwards adopted as probable by Gerhardt, and recently supported by Schrötter, Redtenbacher, and Schneider,—demands the following percentage proportions of its constituent elements:—

$$C_6H_7N_3O_{11}=C_6\left\{\begin{matrix}H_7\\3NO_2\end{matrix}\right\}O_5.$$

Carbon	72	24·24
Hydrogen	7	2·36
Nitrogen	42	14·14
Oxygen	176	59·26
	297	100·00

The formula recently adopted by Pélouze and Maury, as agreeing closely with the results which they obtained in their experiments, requires the following numerical proportions:—

$$C_{24}H_{18}O_{18},\ 5NO_5,\ \text{or}\ C_{24}H_{36}O_{18},\ 5N_2O_5.$$

Carbon	288	25·00
Hydrogen	36	3·13
Nitrogen	140	12·15
Oxygen	688	59·72
	1152	100·00

The following statement shows the relation which the extreme and mean results, obtained in the numerous analytical examinations of gun-cotton manufactured at Waltham Abbey, bear to the two above formulæ:—

Trinitro- or trinitric cellulose.		Results of analysis.			Formula of Pélouze and Maury.
		Extremes.		Means.	
Carbon	24·24	23·71	24·26	24·02	25·00
		24·11	24·59	24·42	
		24·06	24·60	24·15	
		24·21	24·78	24·57	
Hydrogen	2·36	2·40	2·47	2·46	3·13
Nitrogen	14·14	13·36	14·60	13·83	12·15
Oxygen	59·26				59·72

In comparing the experimental results with the requirements of the two different formulæ, it is necessary to bear in mind the following circumstances:—

1. The gun-cotton examined has not been obtained from *pure* cellulose (for the production of which the most elaborate system of purification has been proved to be

necessary), but has been prepared from cotton separated from foreign matters as far as it is possible by the ordinary method of purification adopted.

2. Ample proof has been furnished, by most extensive and rigorous experiments, of the invariable existence in the purified gun-cotton (as produced by the most complete action of the strongest acids upon cotton-wool, purified by treatment with alkali and washing) of notable proportions of substances which owe their existence to the presence of foreign matters remaining in the cotton fibre after its ordinary purification, and also of products resulting from the less perfect action of nitric acid upon small portions of the cellulose.

3. Although these two varieties of impurities were extracted as far as possible by repeated digestion and washing with ether and alcohol, from the pyroxylin analyzed, their perfect removal from the fibre, by the application of any feasible method of purification, is extremely difficult, if not impossible.

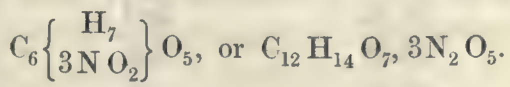
4. The existence of even small proportions of these impurities in a sample of pyroxylin will have the effect of raising somewhat the percentage of carbon, obtained by analysis of the substance, above that which would be furnished by the pure material, and also, consequently, of reducing to a trifling extent the proportion of nitrogen obtained, below the theoretical requirement.

A proof of this is furnished by the analytical results obtained with specimens of the matter soluble in ether and alcohol, which had been extracted from Waltham Abbey gun-cotton.

These results are as follows:—

	Carbon.	Hydrogen.	Nitrogen.
Specimen 1	30·50	2·91	
Specimen 2	29·18		
	29·28		11·85
Mean results furnished by the gun-cotton after digestion with ether and alcohol	24·15	2·46	13·83

It is believed that the foregoing circumstances must be admitted to account perfectly for the slight variations exhibited, among themselves, by the numerous analytical results which have been quoted. The whole of the carbon-percentages obtained by the most trustworthy method of analysis (Method IV.) are somewhat higher, and the great majority of the results of the nitrogen determinations are a little lower than required by the formula



$$C_6\left\{\begin{matrix} H_7 \\ 3NO_2 \end{matrix}\right\}O_5, \text{ or } C_{12}H_{14}O_7, 3N_2O_5.$$

On the other hand, making even very full allowance for errors of analysis, and assuming for an instant the possibility that the substance analyzed could be an absolutely pure product, the individual as well as the mean results of the carbon, hydrogen, and nitrogen determinations, are far more closely in accordance with those theoretical requirements, than with the percentage results which should be furnished by a pure substance having the composition more recently assigned to pyroxylin by Pélouze and Maury, viz.,

$$C_{24}H_{36}O_{18}, 5N_2O_5.$$

The analytical results of gun-cotton manufactured at Waltham Abbey according to Von Lenk's directions confirm, therefore, the correctness of the conclusions that the most explosive known variety of gun-cotton is *trinitro-cellulose* or *trinitric cellulose*; and that cotton-wool is converted into this substance by the complete action upon it, in the cold, of a mixture of one part by weight of nitric acid of specific gravity 1·52, and three parts of sulphuric acid of specific gravity 1·84.

In addition to the data furnished by the analytical experiments described in the foregoing, others, bearing upon the composition of gun-cotton, have been furnished by different systems of experimental inquiry.

The relation between the nitrogen and carbonic acid obtained by oxidation of gun-cotton has been determined. For this purpose, Liebig's method of operating was adopted in the first instance; the gun-cotton being prepared and arranged for combustion as in the case of the nitrogen determinations, and the mixed gases collected in successive proportions and examined*. A few experiments rendered it evident, however, that this method, when applied to the examination of gun-cotton, did not furnish trustworthy results. In the decomposition of this substance, when distributed through a very large proportion of oxide of copper, the oxidation of the carbon does not proceed uniformly; small portions of that element evidently escape oxidation in the first instance, and are only subsequently burned when the nitrogen has already been in great proportion liberated. The proportion which the carbonic acid bears to the nitrogen in the gases successively collected varies therefore, frequently, as the combustion proceeds; and it would consequently be necessary to collect the entire quantity of gases furnished by the gun-cotton operated upon, in order to arrive at a correct result.

The following statement of the relative proportions by volume of the gases collected successively in two operations of this kind, will serve to illustrate the variable composition of the gas collected at successive stages of one and the same operation. In both experiments the gas had been allowed to escape for some time, before the first collection, for expulsion of the air in the combustion-tube.

Experiment I.			Experiment II.		
	Carbonic acid.	Nitrogen.		Carbonic acid.	Nitrogen.
1st tube.	80	20	1st tube.	77·45	22·55
2nd „	78·75	21·25	2nd „	79·76	20·24
3rd „	79·29	20·71	3rd „	79·45	20·55
4th „	79·15	20·85	4th „	79·83	20·17
5th „	83·42	16·58	5th „	78·56	21·44
			6th „	77·06	22·94

---

* This method of examination appears, from the description given in their report, to have been the one adopted by Pélouze and Maury in their determinations of the relative proportions of carbonic acid and nitrogen furnished by gun-cotton.

The majority of results obtained in each of the above experiments are concordant among themselves, and agree closely with the percentage proportions (by volume) of carbonic acid and nitrogen which should be furnished by trinitro-cellulose (namely 80 of carbonic acid to 20 of nitrogen). But in each experiment somewhat discordant results were obtained, and therefore this method of determining the relation between the carbon and nitrogen in gun-cotton was abandoned as not sufficiently trustworthy. It should be observed, however, that even the mean of the several results obtained in each experiment corresponds much more closely with the volume-proportion which should be furnished by trinitro-cellulose, than with that demanded by the formula which Pélouze and Maury adopt, as the following comparison shows:—

	Theory.		Experiment.	
	$\text{Ͼ}_{24}\text{H}_{36}\Theta_{18}5\text{N}_2\Theta_5$	$\text{Ͼ}_6\text{H}_7\Theta_5 3\text{N}\Theta_2$	1.	2.
Nitrogen . .	17·2	20	21·28	19·88

Several determinations of the relative proportions of carbonic acid and nitrogen have been made by Bunsen's method. The mode of operating was as follows: into a very stout wide Bohemian glass tube, about 22 centimetres long and sealed at one end, were introduced, first some reduced copper, then about 0·1 to 0·15 grm. of the dry gun-cotton, and afterwards sufficient oxide to fill about 4 centimetres of the tube. The open extremity of the latter was constricted, and sealed when air had been exhausted. The gun-cotton was then decomposed by applying the flame of a lamp for a short time to the tube. After the oxide of copper had been distributed over the surface of the tube (to the interior of which it adhered, in consequence of the deposition of water from the exploded gun-cotton upon the glass), the latter was introduced into a vessel of wrought iron, within which it was compactly surrounded on all sides by very fine sand. The vessel consisted simply of a piece of gas-pipe about 25 centimetres long and of 3 centimetres internal diameter, closed at one end by means of a plug welded into it, and provided at the other extremity with a screw-cap. A few small perforations were drilled into the sides of the pipe. The glass tube was exposed in this envelope to a red heat for about one hour; when cold, it was opened under mercury, and the gas transferred and examined in the usual manner. The results thus arrived at, which will be quoted presently, were very concordant, and stood in close relation to the results obtained by the separate determinations of carbon and nitrogen in gun-cotton.

The reproduction of cotton from pyroxylin by Hadow's method has been made the subject of many experiments, with the view of controlling by its means the analytical and synthetical results obtained. It was found that by submitting purified insoluble gun-cotton to the action of an alcoholic solution of potassic sulphhydrate, as directed by Hadow, the amount of cotton obtained corresponded closely to the theoretical proportion to be furnished by trinitro-cellulose.

The following results may be quoted as examples. They were obtained with gun-cotton which contained only small proportions of matter soluble in ether and alcohol. From 4·064 grms. to 4·898 grms. of substance were employed.

Description of gun-cotton.	Cotton obtained.	Cotton to be furnished by trinitro-cellulose.
Austrian, coarse yarn	55·24 per cent.	
,, ,, ,, ...	55·08 ,,	
Waltham Abbey, coarse . . .	55·38 ,,	
,, ,, fine	55·30 ,,	
Laboratory products, No. 1 . .	54·22 ,,	54·54 per cent.
,, ,, No. 2 . .	54·48 ,,	
,, ,, No. 3 . .	54·85 ,,	
,, ,, No. 4 . .	54·16 ,,	
,, ,, No. 5 . .	53·64 ,,	

In conducting experiments on this method of examination, a liability to mechanical loss was observed when a very strong solution of the potassic sulphhydrate was employed, in consequence of the fibre becoming to a considerable extent disintegrated during the digestion; but this can be easily avoided by employing the reagent in a more dilute form. The solution best adapted for effecting the complete reduction of gun-cotton by digestion in the cold without breaking up the fibre, was obtained by preparing a saturated solution of potassic hydrate, completely saturating this with sulphhydric acid, and diluting the liquid thus obtained with half its volume of alcohol.

A small loss of product occurs generally, even when the sulphhydrate-solution is not stronger than just described, in consequence of a feeble solvent action exerted by the liquid upon the *reduced* cotton*. In one experiment a sample of cotton obtained from gun-cotton sustained a loss of 0·6 per cent. by digestion in the cold for forty-eight hours with the sulphhydrate.

A slight excess (about 0·5 per cent.) is sometimes exhibited by the weight of the reduced cotton over the amount which should be furnished, theoretically, by pure trinitro-cellulose. In order to ascertain how far this might be ascribed to the retention of sulphur by the cotton under treatment, a very careful examination of several specimens was instituted. A faint odour of sulphurous acid was sometimes observed when the reduced cotton was burned, and in two or three instances the cotton sustained a slight loss (from 0·1 to 0·3 per cent.) upon being digested and washed with carbonic bisulphide; but in other instances the proportion present was only very minute, and the cotton was generally found to be quite free from sulphur.

A comparison between the ash existing in the gun-cotton operated upon, and the quantity remaining in the reduced cotton, showed that no proportion of an excessive result can be ascribed to an accumulation of that constituent. Although the amount of gun-cotton operated upon is about double that of the cotton recovered, the latter was found to contain the smallest proportion of ash. Thus,

---

* Cotton, in the original form of carded wool, is not dissolved by the potassic sulphhydrate.

Expt.	Gun-cotton employed contained	Cotton obtained contained
1.	1 per cent.	0·56 per cent.
2.	1 "	0·74 "

It is evident that the mineral impurities which, during the washing operations, have attached themselves to the gun-cotton fibre, become partially detached during the digestion in potassic sulphhydrate, and the subsequent washing.

Some combustions made of the reduced cotton furnished proportions of carbon and hydrogen which, though according fairly with the requirements of pure cellulose (allowance being made for the ash in the specimens analyzed), were somewhat below the theoretical numbers:—

	Experiment 1.	Experiment 2.	Cellulose.
Carbon	43·98	43·85	44·44
Hydrogen . . .	6·11	6·15	6·17

The specimens analyzed were carefully examined for nitrogen, and very small quantities were detected. The deficiencies of the carbon obtained from them may, therefore, be to a slight extent ascribable to minute portions of the nitro-product having escaped reduction. A still greater influence upon the results must, however, be exerted by the invariable existence of small quantities of foreign organic substances in the samples operated upon.

The slight excess obtained, in many instances, above the theoretical amount of cotton may, it appears, be occasionally due to some extent to accidental causes, but it is mainly to be ascribed to the presence in the specimen examined of a proportion of material resulting from the less perfect action of nitric acid upon some portions of the cotton fibre. Unfortunately, however, the fluctuations in the results which may be furnished by different examinations of the same specimen of gun-cotton by this method, though they might be regarded as not very important in an ordinary analytical process, may be equivalent to differences which would be caused by very considerable variation in the amount of soluble gun-cotton present in the substance.

The proportions of cotton which should be furnished by pure trinitro-cellulose, and by the lower products which HADOW has examined, are as follows:—

			Cotton.
$Ȼ_6 H_7 Ɵ_5$, $3 N Ɵ_2$, or	$Ȼ_{18} H_{21} Ɵ_{15}$, $9 N Ɵ_2$	furnishes	54·54 per cent.
Compound B . .	$Ȼ_{18} H_{22} Ɵ_{15}$, $8 N Ɵ_2$	"	57·45 "
Compound C* . .	$Ȼ_{18} H_{23} Ɵ_{15}$, $7 N Ɵ_2$	"	60·67 "

---

* A product possessing the properties of compound C, described by HADOW, and agreeing closely in its composition with the requirements of the formula assigned to that body, has been manufactured in considerable quantities at Waltham Abbey, for experimental purposes, by submitting cotton-yarn to digestion for the customary

Supposing that the matter soluble in ether and alcohol in a specimen of gun-cotton amounted to 2 per cent., and consisted of the compound C, the result of the analysis should be affected by that impurity to the extent of about 0·1 per cent. An excess of 0·5 per cent. obtained in the examination of a sample should therefore indicate the existence of 10 per cent. of compound C (readily soluble gun-cotton) in the sample; or if the specimen contained that percentage of compound B, this would only affect the result by 0·3 per cent. It cannot be confidently asserted that the errors of the method itself are ever less than from 0·3 to 0·5 per cent.

It is evident, therefore, that this method of examining gun-cotton, though useful as a mode of controlling the results obtained by determining the increase of weight which cotton sustains by treatment with nitric acid, under varied circumstances, is not susceptible of affording sufficiently definite and trustworthy results to render it applicable as a method of ascertaining the degree of freedom from soluble gun-cotton, of products of manufacture.

Experiments on the increase sustained by cotton in its conversion into gun-cotton.—HADOW found that cotton-wool, by treatment with the strongest mixture of nitric and sulphuric acids, sustained an increase of 81·34 per cent., that the gun-cotton produced was quite insoluble in mixtures of ether and alcohol, and that the increase of weight which cellulose should sustain by conversion into the trinitro-cellulose agreed very nearly with the results of his experiment.

PÉLOUZE'S earlier experiments fixed the *maximum* increase in weight sustained by cotton upon conversion into gun-cotton at 76 per cent. But in the recent report of PÉLOUZE and MAURY it is stated that, in a number of laboratory experiments in which the composition of the acid-mixture, the proportions borne by the acid used to the cotton treated, and the duration of the treatment, were variously modified, the increase in weight of the cotton fluctuated within narrow limits, and did not exceed 78 per cent. The authors are led, mainly by these results, to adopt the formula

$$\text{Ȼ}_{24}H_{36}\text{Ɵ}_{18},\ 5N_2\text{Ɵ}_5,$$

---

period with an acid-mixture which differed from that employed in the manufacture of insoluble gun-cotton, in containing $3H_2O$ in addition.

The substance possessed feeble explosive properties, was readily soluble in ether and in glacial acetic acid, with the exception of a small proportion of foreign matter, which rendered the solution slightly turbid. The results obtained by determinations of carbon and nitrogen in the substance corresponded very closely to the proportions which should be furnished by $C_{18}H_{23}\text{Ɵ}_{15}, 7N\text{Ɵ}_2$, as the following comparison shows:—

		Theory.		Experiment.		
Carbon . . .	18 =	216 =	26·97	27·08	27·01	27·17
Nitrogen . . .	7 =	98 =	12·23	12·42	12·41	
Hydrogen . .	23 =	23 =	2·87			
Oxygen . . .	29 =	464 =	57·93			
		801	100·00			

because cellulose, by conversion into a substance having the percentage-composition which that formula demands, should sustain an increase of weight of 77·78; a number which is very slightly *below* the maximum result obtained in their experiments.

It should be stated that they describe the acids employed by them in all their experiments as follows: the sulphuric acid had a density of 66° BAUMÉ (which corresponds to a specific gravity of 1·767), and the nitric acid had a specific gravity of 1·50 at 9° C.

It will be observed that these acids, but more especially the sulphuric acid, are very notably inferior in strength to those prescribed by Von LENK, which have been used in all the experiments now described, and are always employed in the manufacture of gun-cotton at Waltham Abbey; namely, sulphuric acid of specific gravity 1·833 to 1·84 (somewhat above 69° BAUMÉ), and nitric acid of specific gravity 1·52 at 15° C. It appears most probable, from many of the experimental observations included in these researches, that such discrepancies as exist between the results arrived at by PÉLOUZE and MAURY, and by HADOW, the German chemists and myself, are to be mainly ascribed to the differences in the strength of acids employed.

The subjoined results of very numerous experiments will, I believe, be admitted not only to establish satisfactorily the correctness of HADOW's statement, that cotton-wool may be made to sustain an increase in weight above 81 per cent., but also to show that the results of other experimenters who have found the increase sustained by cotton not to exceed 78 per cent., are in perfect harmony with the conclusion that the product of the complete action, upon cotton-wool, of certain mixtures of the strongest nitric and sulphuric acids, *is the substance*

$$\text{Ꞓ}_6\,\mathrm{H}_7\,\mathrm{N}_3\,\Theta_{11},$$

in a nearly pure condition.

The following statement shows the increase of weight which finely carded cotton-wool of very high quality, previously purified by treatment with alkali and washing, has sustained by single and successive digestions, for different periods, with the prescribed acid-mixture. The products were always purified by careful washing with distilled water.

No. of experiments.	Quantity of cotton operated upon.	Proportion of acid to cotton.	Duration of treatment.	Temperature of acid used.	Increase in weight on 100 of cotton.
1	3·704 grms. submitted to six successive treatments.	From 60 to 70 parts of acid to 1 part of cotton.	1st treatment, 1 hour.	15° C.	79·40
			2nd treatment, 3·5 hours.	,,	79·96
			3rd treatment, 18 ,,	,,	80·26
			4th treatment, 18 ,,	,,	82·13
			5th treatment, 48 ,,	,,	81·28
			6th treatment, 48 ,,	,,	80·26
2	3·087 grms.	50 to 1	48 hours.	,,	81·86
3	1·132 grm.	,,	24 ,,	,,	82·57
4	1·263 ,,	,,	24 ,,	,,	82·04
5	1·083 ,,	14·6 to 1	24 ,,	,,	80·07
6	3·222 grms.	10 to 1	48 ,,	,,	78·79
7	1·907 grm.	10 to 1	12 ,,	,,	78·13
8	2·468 grms.	50 to 1	10 minutes.	,,	62·43
9	1·668 grm.	50 to 1	15 ,,	55° C.	78·98

Experiment 1 shows that a repeated immersion of the gun-cotton in a fresh mixture of the acids raised the weight of 100 parts of cotton to 182·13, a number somewhat higher than that obtained by HADOW; but that, by protracting the treatment beyond the point when the product ceased to increase in weight, a slight but continuous loss was sustained, which, there appears no doubt, from the results of confirmatory experiments, is to be ascribed to the solution of small quantities of gun-cotton in the strong acids with which it was left in prolonged contact.

The following results show that the *repeated* immersion of cotton in an acid-mixture of somewhat less strength, does not effect, nearly as rapidly or as completely, its conversion into insoluble gun-cotton, as does a single treatment with the acid-mixture prescribed by Von LENK.

(*Experiment* 10.)—2·12 grms. of pure dry cotton were submitted to two successive treatments with a cold mixture of acids having the composition

$$\left.\begin{matrix} HNO_3 \\ H_2SO_4 \end{matrix}\right\} + 3H_2O^*.$$

Period of first immersion three hours, increase in weight . . 62·34 per cent.

Period of second immersion nine hours, increase in weight . 65·14 per cent.

The product was then digested for three hours in the cold with the strongest acid-mixture, after which the total increase in weight was 77·51 per cent.

Experiments 2, 3, and 4 prove that, by a single treatment of cotton with a considerable proportion of the strongest acid-mixture, results may be obtained closely in accordance with the number given by HADOW, and with the theoretical requirement of trinitro-cellulose. The mean of these three experiments fixes the maximum increase in weight which cotton is capable of attaining by this treatment at 82·16 per cent.; the theoretical number is 83·3 per cent.

Experiments 5, 6, and 7 show that, even in operating upon small quantities of comparatively very pure cotton, if the proportions of the acid-mixture used be limited to such as are employed in manufacturing operations (10 to 14 parts to 1 of cotton), the conversion into trinitro-cellulose cannot be as completely accomplished. In these instances, the increase of weight sustained by the cotton is between 78 and 80 per cent. As might have been anticipated, the products contained notable proportions of matter soluble in ether and alcohol, while those obtained in experiments 2, 3, and 4 yielded a minute trace to the solvent.

Experiment 8 demonstrates the importance of continuing the digestion with acids longer than is merely necessary for the production of an explosive material, if it is desired to effect as complete a conversion as possible into insoluble gun-cotton. By immersion for ten minutes only, the cotton increased in weight only 62·43 per cent., and the product was to a considerable extent soluble in ether and alcohol. In another experiment, a still more soluble product was obtained by immersion for only three minutes. Experiments 6 and 7 indicate that, the quantity of acid used being limited, digestion for twelve hours is scarcely sufficient to ensure the maximum attainable increase of weight; and the results of experiments 3 and 4, compared with those of 1 and 2, indicate that under equal conditions, the result obtained by immersion for twenty-four hours is quite equal to that furnished by more protracted digestion. This observation is fully borne out by the results of manufacturing operations, as pointed out in the first part of this memoir. There is no doubt that an actual loss of product, though only slight, is sustained by prolonging the contact of the acids with the gun-cotton much beyond the period necessary for its perfect production.

---

* This is the composition of the mixture which HADOW believes to be the weakest which is capable of producing insoluble gun-cotton by repeated immersions. The nearest expression of the composition of Von LENK's acid-mixture is $\left\{\begin{matrix} 10\,HNO_3 \\ 19\,H_2SO_4 \end{matrix}\right.$.

Experiment 9 shows that a very brief treatment of cotton with a warm acid-mixture effects its conversion into insoluble gun-cotton as completely as a long-continued treatment with cold acids (the proportion of the latter being limited). This experiment was made for the purpose of ascertaining whether, with the employment of the strongest acids, heat exerted a similar influence upon the character of the product to what it does when weaker acid-mixtures, or mixtures of saltpetre and sulphuric acid are employed. This is evidently not the case, for the product obtained was as slightly soluble as the general products of manufacture at Waltham Abbey. It was also found that a few minutes' immersion in a warm acid-mixture converted an imperfect product, obtained by a few minutes' treatment with *cold* acids and containing much soluble matter, into a gun-cotton of the ordinary kind.

The following results were obtained by submitting samples of cotton-yarn (taken from ordinary supplies for the manufacture of gun-cotton) to treatment with the usual mixture of acids, the cotton having previously been boiled in an alkaline bath and washed; after which treatment it still retained a very few fragments of seed.

Experiment.	Cotton employed.	Duration of immersion.	Increase in weight on 100 parts of cotton.
11	4·777 grms.	48 hours	78·43
12	8·076 „	48 „	78·19
13	6·0206 „	24 „	80·77
14	6·901 „	24 „	80·79
15	9·2147 „	48 „	78·14

In all these experiments a considerable excess of acids (about 60 parts to 1 of cotton) was employed. They afford decided evidence of the influence which the quality of the cotton employed must exert upon the quantity of product obtained even in a laboratory operation; and show that the results furnished, under most favourable circumstances, by cotton of ordinary commercial quality, fluctuate between 78 and 81 per cent., never quite reaching the latter number. The results also point, as did some of those obtained with the purer cotton, to a tendency of the gun-cotton to dissolve in the acid-mixture when the immersion is continued for a very long period. Both results (experiments 13 and

14) obtained by treatment of the cotton for twenty-four hours are notably higher than those furnished by the forty-eight hours' treatment. The loss of product ascribable to this cause is doubtless somewhat greater in these experiments than in manufacturing operations, when the proportion of acid to the cotton used is considerably lower*.

A comparison of the weight of cotton, obtained from samples of gun-cotton, with the original weight of cotton employed in their production, affords data which are strongly in support of the conclusion that the differences between the increase in weight which cotton should sustain by conversion into trinitro-cellulose,

$$\mathrm{C}_6\,\mathrm{H}_7\,\mathrm{N}_3\,\mathrm{O}_{11},$$

and the results furnished by as perfect a treatment of different specimens of cotton as is practicable, are to be ascribed, not merely to the presence, in the products, of small quantities of imperfectly converted soluble gun-cotton, but also to the existence in them of substances which are foreign to the cotton, and which are only partially removeable by simple washing with water.

The following are the results of very careful experiments made with finely-carded and specially purified cotton-wool, and with ordinary cotton-yarn, purified by boiling with potassic carbonate. The increase sustained by the cotton upon its conversion into gun-cotton having been noted, the product was reconverted into cotton by HADOW'S method, special care being taken to avoid mechanical loss in the several operations. The weights of the cotton recovered compared with those of the original cotton, and with the increase of weight sustained by the latter when converted into gun-cotton, are as follows:—

Description of cotton.	Proportion of acids to cotton.	Increase sustained by conversion.	Cotton employed.	Cotton recovered.	Loss upon the original cotton.
		Per cent.	grms.	grms.	Per cent.
Finely carded and purified.	50 to 1	82·57	1·132	1·119	1·14
Ditto.	Ditto.	82·04	1·263	1·2526	0·83
Ditto.	14·6 to 1	80·07	1·083	1·0695	1·24
Cotton-yarn, ordinary quality.	60 and 70 to 1	78·43	4·777	4·574	4·43
Ditto.		78·19	8·076	7·561	6·34
Ditto.		80·77	6·0206	5·6862	5·55
Ditto.		80·79	6·901	6·5319	5·36

It will be seen from the above statement, that the cotton which was recovered from the laboratory products, furnished by comparatively very pure cotton which had sustained an increase of weight of 82 and 82·6 per cent. (the theoretical increase being

---

* Upon reconversion into gun-cotton of some specimens of the reduced cotton, which is always in a friable condition very favourable to solution, the weights of the resulting products indicated that a more considerable proportion of the gun-cotton produced was dissolved than when the original cotton was operated upon.

One sample sustained an increase of weight of only 73·91 per cent., and a second 73 per cent. by immersion for the usual period. A third sample, submitted to a brief treatment, gave an increase of 77·61 per cent., and upon being immersed a second time for twenty-four hours, the weight of the product indicated an increase of only 75·15 per cent.

83·3 per cent.), amounted to only about 1 per cent. less than the cotton originally taken; and that when the employment of a limited quantity of acid (as in the third experiment) yielded a product the weight of which represented about 2 per cent. less increase than these, the cotton recovered was in this instance also only about 1 per cent. below the quantity employed, the difference in the weight of the nitro-product having been due only to the formation of a somewhat larger proportion of soluble gun-cotton. It appears from these results, and estimating the proportion of loss which the processes of conversion and reduction may involve at about 0·5 per cent., that the particular cotton-wool operated upon contained about 0·5 per cent. of matter foreign to cellulose, which was eliminated in the course of the transformation and reproduction of the latter. But, when less pure samples of cotton were converted as completely as practicable into insoluble gun-cotton, and furnished results from 1·75 to 4 per cent. lower than those obtained by similar treatment of the pure material, the weight of the recovered cotton indicated a loss upon the original substance employed of from 4·4 to 6·3 per cent., an increased loss which must be due to the larger proportion of foreign matters existing in the cotton operated upon. These facts surely afford strong support to the conclusion that the deficiency in weight exhibited by the products obtained from ordinary cotton-wool, even after its purification with alkali, as compared with those furnished under the same circumstances by purer cotton-wool, is due to the presence of foreign matters in the cotton, which, though partially retained by the gun-cotton, exist there in the form of products whose formation does not add, in so high a proportion, to the original weight of the cotton as does the production of trinitro-cellulose.

It follows from the above results, obtained by treatment of the ordinary cotton-wool with a considerable excess of acid, that if the same cotton be treated with the limited proportion of acid-mixture (10 to 14 parts by weight to 1 part of cotton) employed in the ordinary course of manufacture, the products must then exhibit somewhat less increase of weight (lower proportions, therefore, than 178 or 180 from 100 of cotton), because, under those circumstances, the production of larger proportions of the lower cellulose-products (soluble in ether and alcohol) comes into play to cause a reduction in the weight of the product beyond that which is ascribable mainly to the influence of the foreign matters in the cotton.

Two quantitative operations have been conducted in the ordinary course of manufacture at Waltham Abbey, with the view of ascertaining the actual quantity of gun-cotton furnished by 100 parts of cotton in the ordinary course of operating with considerable quantities of material.

In one experiment the cotton employed, which contained about the average quantity of seed, and had as usual the peculiar colour of unbleached fibre, was submitted to the ordinary purification in the bath of potassic carbonate, and was dried as usual for twenty-four hours at 50° C. before immersion in acids. Its weight, when dry, was 31 lbs. 6 oz. It was afterwards treated in all respects like an ordinary product of manufacture. The weight of the air-dry gun-cotton showed an increase upon the original dry cotton of

74·3 upon 100 parts. The weight of the thoroughly dry product corresponded to an increase of 71 upon 100.

In another experiment, made with a somewhat higher quality of cotton, an increase of 76 per cent. was obtained.

The products of these operations were quite similar in character to those usually obtained, and to the results furnished by the laboratory-experiments just now described, which were conducted with samples of the same description of cotton. A difference of about 9 per cent. between the latter results and the lowest number furnished by the quantitative manufacturing experiments has therefore to be accounted for. The following statements will show that this deficiency is not greater than would be anticipated.

In the cotton operated upon, besides the resinous and other impurities which are partly removed by solution in the acid and by subsequent extraction in the purifying processes, and which also occasion a notable loss in the laboratory-experiments with this kind of cotton, as already pointed out, there exists a more or less considerable proportion of seed, of which only minute particles are here and there observed in the finished gun-cotton. To this source of loss upon the weight of the cotton employed, has to be added the mechanical loss of product unavoidably attending the repeated submission of the gun-cotton to the expressing and long-continued washing processes. But the principal loss of product, and one which alone suffices to account for the difference observed between the results of the laboratory-experiments and those of ordinary manufacturing operations, occurs in boiling the gun-cotton in the alkaline bath. The brief digestion of the material in the weak solution of potassic carbonate not only abstracts a considerable proportion of the products foreign to gun-cotton, resulting from the action of the acids upon the impurities which the cotton fibre obstinately retains, but also causes a very notable proportion of the gun-cotton itself to pass into solution.

A quantity of Waltham Abbey gun-cotton which had, in the ordinary course, already been submitted to the treatment with alkali, was boiled for ten minutes in a solution of potassic carbonate precisely similar to that usually employed (of spec. grav. 1·02). The liquid became of an amber colour, and the gun-cotton, when dried, was found to have sustained a loss of 3·7 per cent. The same gun-cotton was again boiled for twenty minutes in the same alkaline bath, which deepened in colour considerably during this second employment. The total loss sustained by the material, after this second treatment, amounted to 12·09 per cent.*

9·22 grms. of cotton yarn, previously purified by treatment with alkali and carefully freed from seed, were converted into gun-cotton in the ordinary manner, excepting that about three times the ordinary proportion of acid was used, whereby the solution of foreign matters in the acid was promoted. The product, after long-continued washing in distilled water, was dried and weighed. The increase sustained by the cotton amounted to 78·14 per cent. (a number closely corresponding to the laboratory-results previously described). The gun-cotton was then boiled for eleven minutes in a solution of potassic carbonate of the usual strength. When washed and again dried, it was found to have lost considerably in weight, and the finished product showed an increase of weight upon the original cotton equivalent to 69·8 upon 100, which was therefore 1·2 per cent. less than the lowest result obtained in the manufacturing operations. It is easily conceivable that, in the smaller operations, the gun-cotton, though submitted only for exactly the usual period to treatment with an alkaline bath of the ordinary strength, should sustain a somewhat greater loss than a large compact mass of the material, such as is always operated upon. But the results of these experiments establish a source of loss in the usual process of manufacture, which fully accounts for the discrepancies exhibited between the yields of usual manufacturing operations and of laboratory operations conducted with the same description of cotton, in which the treatment with boiling alkaline water has been omitted.

---

* The treatment of gun-cotton with a boiling solution of potassic carbonate of the prescribed strength, even if greatly prolonged, does not affect the composition of the mass, but evidently acts by dissolving, and transforming into other products, portions of the fibre, or of its surfaces. The combustion of a specimen of ordinary gun-cotton which had been boiled for one hour in the alkaline bath furnished 24·48 per cent. of carbon (the theoretical number of trinitro-cellulose being 24·24 per cent.).

Comparison between analytical and synthetical results.—The relative proportions of carbonic acid and nitrogen furnished by the complete oxidation of gun-cotton, afford the means of instituting a comparison between the analytical and synthetical results, of which the details have been given, and, it is believed, of demonstrating beyond dispute the correctness of the conclusion, that the product of the complete action upon cotton-wool of the mixture of strongest acids prescribed by Von LENK is most correctly represented by the formula

$$C_6 H_7 N_3 \Theta_{11},$$

of which the expression

$$C_6 H_7 \Theta_5, 3N \Theta_2$$

appears to be the most rational interpretation. The method of determining the relative proportions of the two gases furnished by gun-cotton has been already described. The following results were furnished by four samples of gun-cotton:—

	Volume proportions of carbonic acid and nitrogen.		Proportions required by
	I.	II.	$C_6 H_7 N_3 \Theta_{11}$.
Carbonic acid . .	62·25=81·22	76·899=80·91	80
Nitrogen . . .	14·40=18·78	18·144=19·09	20
	III.	IV.*	$C_{24} H_{36} \Theta_{18} 5N_2 \Theta_5$.
Carbonic acid . .	83·64=80·91	72·397=80·91	82·8
Nitrogen . . .	19·73=19·09	17·082=19·09	17·2

---

[*] A sample of gun-cotton which had been left in contact with acids for five days, and a second sample, which had been twice submitted to the ordinary treatment with acids, furnished the following results:—

	5 days in acid.	Twice dipped.	Trinitro-cellulose.
Carbonic acid . . .	80·574	80·37	80
Nitrogen	19·426	19·63	20

The proportion of nitrogen furnished by the first experiment, though somewhat low, is nearer to the requirements of the trinitro-cellulose formula than to those of the formula adopted by PÉLOUZE and MAURY; the proportions of the gases observed in the other three experiments, which happen to be identical in their results, correspond with the requirements of $C_6 H_7 N_3 O_{11}$ as closely as could possibly be expected when operating upon a substance of approximate purity only.

Upon calculating the proportion which the nitrogen found in these experiments bears to the mean percentage of carbon (24·6) obtained by the most trustworthy method employed for the determination of that element, the following numbers are obtained:—

	I.	II., III., & IV.
Carbon	24·6	24·6
Nitrogen	13·32	13·59

These percentage-proportions of nitrogen are not only in perfect accordance with a considerable number of the results obtained by direct determination of the volume of nitrogen furnished by samples of Waltham Abbey gun-cotton, they are also as close approximations to the theoretical percentage of nitrogen in trinitro-cellulose as the analysis of products containing small proportions of lower nitro-compounds could be expected to furnish; and lastly, the increase in weight which cotton of average purity should sustain by conversion into nitro-cellulose-products which furnish these proportions of nitrogen, corresponds closely to the average results obtained by operating upon moderately pure cotton with the mixed acids of *prescribed strength* and in the proportion (about 10 parts to 1 of cotton) indicated by Von LENK.

The general conclusions to be deduced from the experimental results described in this memoir are as follows:—

1. The products obtained by submitting cotton-wool to treatment with the prescribed mixture of nitric and sulphuric acids, and to purification as directed by Von LENK, are very uniform in character; they consist almost entirely of the most explosive known variety of gun-cotton or pyroxylin, which is insoluble in mixtures of ether and alcohol. This substance, when produced upon a manufacturing scale, contains from 1 to 2 per cent. of mineral substances, and a small proportion, varying with the quality of the cotton, of matters soluble in alcohol, partaking of acid properties, and consisting chiefly, if not entirely, of products of the action of nitric acid upon resinous or other bodies enclosed in the cotton fibre. There is also always present in the gun-cotton a small quantity (from 1 to 3 per cent.) of cellulose-products of a less explosive character, soluble in mixtures of ether and alcohol, which result from the incomplete action of nitric acid upon small portions of the cotton operated upon.

2. The gun-cotton, when purified as far as it is possible from foreign substances, soluble in alcohol and in ether and alcohol, furnishes analytical results which agree much more closely with those demanded by the formula

$$C_6 H_7 N_3 O_{11}, \text{ or } C_6 H_7 O_5, 3N O_2,$$

than with the requirements of the formula

$$C_{24} H_{36} O_{18}, 5N_2 O_5,$$

recently adopted for gun-cotton by PÉLOUZE and MAURY.

3. If cotton-wool of great purity is digested for a period of about twenty-four hours with a considerable proportion of the prescribed acid-mixture (about 50 parts to 1 of cotton), it sustains an increase of weight ranging between 81·8 and 82·6 upon 100 of cotton. Lower results (between 78 and 80 per cent. increase) are obtained by digesting the cotton for a short period only, or for very considerable periods, by using a limited proportion of the acid (from 10 to 14 parts to 1 of cotton), by employment of acids of slightly lower specific gravities than those specified, and by operating upon cotton of somewhat lower quality. The digestion, for a second or third time, of products which have exhibited a comparatively low increase of weight, in an acid-mixture of the kind first used, or of greater strength, has the effect of raising the weight of the product to within the higher limits above named.

The increase in weight which 100 parts of pure cellulose should sustain, theoretically, by complete conversion into a substance of the composition $C_6 H_7 N_3 O_{11}$, is 83·3, while, if converted into a substance of the formula

$$C_{24} H_{36} O_{18}, 5N_2 O_5,$$

the increase sustained by it only amounts to 77·8 upon 100 parts.

4. Cotton-wool always contains, even after careful purification, small proportions of foreign organic substances, the presence of which, in the material submitted to treatment with the acids, must affect to some extent the quantity of the product obtained.

5. It is extremely difficult, indeed apparently impossible, even in operating under most favourable conditions upon small quantities of cotton-wool, to convert this substance *completely* into the highest nitric product—the perfectly insoluble gun-cotton. Small quantities of gun-cotton soluble in ether and alcohol can always be extracted from the products; the quantities are only minute in the highest laboratory-products, but they are always very appreciable in the most perfect manufacturing products. Their invariable formation must unquestionably cause the increase of weight sustained by cotton to be somewhat less than that which theory would demand.

6. The long-continued digestion of the gun-cotton in the acid-mixture, the several mechanical operations to which it is submitted in the course of its purification, and above all, the solvent action exerted not only upon certain bye-products, but also upon the gun-cotton itself by the alkaline liquid, in which it is boiled for a short time, are all sources of loss which, in examining into the results of a system of manufacture, must not be disregarded, and the existence of which explains satisfactorily the difference observed between the weights of laboratory-products and those of manufacturing operations.

7. In accepting the formula proposed by PÉLOUZE and MAURY for gun-cotton, it

would be necessary to assume that the cotton-wool operated upon was pure cellulose; that the operation of conversion was an absolutely perfect chemical process; that there were no possible sources of loss in the production of the material; and that in all laboratory operations which had furnished an increase of weight above the theoretical demand (77·8 per cent.), some substance, differing in composition from the ordinary products of manufacture, must have been obtained.

8. The identity in their characters, and close resemblance in composition, of the most perfect products of laboratory operations and of the *purified* products of manufacture, the very close approximation in the weight of the former to the theoretical demands of the formula

$$C_6 H_7 N_3 O_{11}$$

(which may be expressed as

$$C_6 H_7 O_5,\ 3N O_2,\ \text{or}\ C_{12} H_{14} O_7,\ 3N_2 O_5),$$

and the satisfactory manner in which the unavoidable production of somewhat lower results in the manufacturing operations admits of practical demonstration, appear to afford conclusive evidence of the correctness of either of those formulæ as representing the composition of the most explosive gun-cotton, and to demonstrate satisfactorily that the material, prepared strictly according to the directions perfected by Von Lenk, consists uniformly of that substance (now generally known as *trinitro-cellulose*) in a nearly pure condition.

The products furnished by the explosion of gun-cotton under varied conditions are at present being investigated by me; and the behaviour of the substance (as obtained in ordinary manufacturing operations), when exposed to light, heat, and other agencies tending to promote chemical change in bodies of unstable character, is also being carefully examined into. The results of these branches of the general inquiry into the history of pyroxylin will be communicated to the Royal Society in due course; meanwhile it should be stated that numerous experiments already instituted, which bear upon the stability of gun-cotton, have furnished results differing in very important respects from those recently published in France.

XV. *Researches on Acids of the Lactic Series.*—No. I. *Synthesis of Acids of the Lactic Series.* *By* E. Frankland, *F.R.S., Professor of Chemistry in the Royal Institution of Great Britain and in the Government School of Mines; and* B. F. Duppa, *Esq.*

Received February 14,—Read March 1, 1866.

With the exception of the acetic series, no family of organic acids has excited so much interest amongst chemists, and been the subject of such numerous researches, as that represented by lactic acid. Its character, intermediate between the monobasic and dibasic acids, its close relations to the acetic and acrylic families, and the numerous important transformations which it undergoes, have all contributed to render this family an attractive subject for experimental inquiry and a fruitful source of theoretical speculation. These inquiries and hypotheses have contributed greatly to the elucidation of the habits of these acids, and still more to the general progress of organic chemistry. Nevertheless there are two circumstances which have materially interfered with their complete success; these are, the comparatively small number of the known members of this series, and the absence of any synthetical proof of the nature of their constituent radicals. These obstacles to a more satisfactory conception of the internal architecture of the acids in question we have endeavoured to remove by the production, according to purely synthetical methods, of a number of new members of this series, a brief notice of which we have from time to time had the honour of submitting to the Royal Society[*], and the more complete history of which we propose to develope in the following pages. Our general method for synthetically producing the acids of the lactic series depends upon the replacement of one of the atoms of dyad oxygen in oxalic acid, or rather in the ethereal salts of oxalic acid, by two atoms of monad alcohol radicals. Such a replacement at once transforms dibasic oxalic acid into a monobasic acid of the lactic series. The nature of this transformation, as well as the relations of oxalic acid to the lactic family, is clearly seen from the following comparison of the formulæ of oxalic acid and of its derivative, dimethoxalic acid:—

$$C_2\left\{\begin{array}{l} O \\ OH \\ \hline O \\ OH \end{array}\right. \text{ or } \left\{\begin{array}{l} COHo \\ COHo \end{array}\right. ;\ \dagger \qquad\qquad C_2\left\{\begin{array}{l} (CH_3)_2 \\ OH \\ \hline O \\ OH \end{array}\right. \text{ or } \left\{\begin{array}{l} CMe_2Ho \\ COHo \end{array}\right. .$$

Oxalic acid. Dimethoxalic acid.

This substitution of alcohol radicals for one atom of oxygen in oxalic acid can be readily effected by acting upon the ethereal salts of oxalic acid by the zinc compounds of the alcohol radicals.

---

[*] Proceedings of the Royal Society, vol. xii. p. 396; vol. xiii. p. 140; vol. xiv. pp. 17, 79, 83, 191, 197, and 198.

[†] In this paper O=16, C=12, H=1, Zn=65, Ba=137, Cu=63·5, Ho=(OH) the monad radical hydroxyl or peroxide of hydrogen, Eto=(OC_2H_5) ethoxyl or peroxide of ethyl, &c.

I. *Action of Zincethyl upon Ethylic Oxalate.*

In this reaction ethylic oxalate * was mixed with rather more than its own volume of pure zincethyl; the temperature of the mixture gradually rose, and large volumes of gas were evolved. This gas, which, as the following analyses prove, consists of about equal volumes of ethylic hydride and ethylene, was passed through a U-tube immersed in ice, and subsequently through sulphuric acid, and was then collected over mercury. It was found to be soluble in an equal volume of strong alcohol, and gave the following numbers on analysis:—

	I.	
	Millimetres of mercury.	Temperature.
Pressure of gas used	237·2	14°·0 C.
Pressure after absorption of $C_n H_{2n}$ by sulphuric anhydride	121·1	14·0 C.
	II.	
Pressure of gas used	29·1	13·0 C.
Pressure after addition of oxygen	278·6	13·0 C.
Pressure after explosion	207·0	13·0 C.
Pressure after absorption of $C O_2$	149·6	13·0 C.
	III.	
Pressure of gas used	27·8	14·0 C.
Pressure after addition of oxygen	304·5	14·0 C.
Pressure after explosion	242·3	14·0 C.
Pressure after absorption of $C O_2$	186·8	14·0 C.

---

* As large quantities of ethylic oxalate were required for this and the following reactions, it became a matter of importance to prepare this compound in the most economical manner. After trying the numerous methods which have been recommended, we found the following process to give the largest product:—

1500 grammes of oxalic acid, thoroughly dried at 100° C., are placed, together with 1000 grammes of absolute methylated spirit, in a capacious retort, which is then very slowly heated by an oil-bath to 100° C., at which temperature water begins to distil over; when the thermometer has risen to 105°, a steady stream of absolute methylated spirit is conducted to the bottom of the retort at the rate of about 80 grammes per hour, the temperature being allowed to rise very slowly to 125°–130° C., care being taken on the one hand that alcohol shall not distil over, in which case the temperature should be raised, and on the other that the heat is not so great as to cause the generation of gas. At this rate it requires about twelve hours to make the addition of 1000 grammes of alcohol; after which the retort must be gradually heated to the boiling-point of ethylic oxalate, and the remainder of the distillate, which is the pure oxalic ether, collected apart. By fractional distillation the first portions afford a considerable additional quantity of the pure product besides ethylic formate. During the final operation, in consequence of the presence of some unconverted oxalic acid, a quantity of gas is always evolved; nevertheless, in frequently repeated operations, we have obtained an amount of pure ethylic oxalate equal in weight to the dried oxalic acid employed.

No. I. shows the amount of hydrocarbon of the form C_nH_{2n}; No. II. gives the results of the combustion of the gas remaining after the action of anhydrous sulphuric acid; whilst No. III. is a combustion of the gas previous to the action of sulphuric anhydride.

No. I. proves that the original gas consisted by volume of

Gas absorbable by SO_3	116·1	or	48·95 per cent.
Gas unabsorbable by SO_3	121·1	or	51·05 per cent.

Analysis No. II. gave the following results:—

Volume of combustible gas	29·1	or	1
Volume of oxygen consumed	99·9	or	3·43
Volume of CO_2 generated	57·4	or	1·97

These numbers show that the gas left unabsorbed by sulphuric anhydride is ethylic hydride, one volume of which consumes on combustion 3·5 volumes of oxygen and generates 2 volumes of carbonic anhydride.

Analysis No. III., taken in connexion with No. II., determines the composition of the gas absorbed by sulphuric anhydride, and proves it to have the composition of ethylene; for 27·8 volumes of the mixed gases consumed 89·9 volumes of oxygen, and generated 55·5 volumes of carbonic anhydride; or

Vol. of comb. gas.		O consumed.		CO_2 generated.
1	:	3·23	:	2·00

whereas 1 volume of a mixture of equal volumes of ethylic hydride and ethylene would consume 3·25 volumes of oxygen, and generate 2 volumes of carbonic anhydride. Hence the original gas consisted of

Ethylene	48·95
Ethylic hydride	51·05
	100·00

This result is confirmed by a determination of the specific gravity of the gaseous mixture, which gave the following results:—

Temperature of room	13°·3 C.
Height of internal above external mercury	0·1 millims.
Weight of flask and gas	29·947 grms.
Temperature in balance-case	18°·3 C.
Weight of flask and air	29·9405 grms.
Temperature in balance-case	18°·3 C.
Height of barometer	746·0 millims.
Capacity of flask	141·6 cub. centims.
Specific gravity of gas	1·0375.

The specific gravity of a mixture of ethylic hydride and ethylene in the above proportions would be 1·0026.

It is therefore evident that this gas results from the decomposition of ethyl according to the following equation,

$$\underset{\text{Ethyl.}}{\left\{\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right.} = \underset{\text{Ethylic hydride.}}{\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}} + \underset{\text{Ethylene.}}{C_2H_4},$$

and that for the attainment of the desired result of the reaction it is best to prevent this secondary decomposition as much as possible. This we succeeded in doing by preventing the temperature from rising beyond 60° C. or 70° C., until the operation was considerably advanced. Afterwards it was necessary to heat to 100° C. to complete the reaction.

The mixture generally continues fluid, but assumes a light straw-colour and a thick oily consistency. On being heated to 130° C. in a retort, no distillate passes over. If, after cooling, its own volume of water be very gradually added, torrents of ethylic hydride are evolved, and, on subsequent distillation in a water-bath, weak alcohol containing an ethereal oil in solution passes over; and a further quantity of the oil may be obtained by adding water to the residue in the retort, and continuing the distillation on a sand-bath. By repeated rectification the alcohol can be approximately separated from the water and oil, whilst the latter may then be removed by a separator.

The oily product so obtained was submitted to rectification, when its boiling-point rapidly rose to 175°, at which temperature the whole of the remaining and very large proportion of the liquid distilled over.

The composition of this liquid is determined by the following analyses:—

I. ·2872 grm. gave ·6261 grm. carbonic anhydride and ·2710 grm. water.
II. ·3009 grm. gave ·6577 grm. carbonic anhydride and ·2767 grm. water.
III. ·2620 grm. gave ·5750 grm. carbonic anhydride and ·2355 grm. water.
IV. ·3223 grm. gave ·7070 grm. carbonic anhydride and ·2917 grm. water.

These numbers coincide closely with those calculated from the formula

$$C_8H_{16}O_3,$$

as is seen from the following comparison of experimental with calculated numbers:—

	Calculated.		I.	II.	III.	IV.	Mean.
C_8 . .	96	60·00	59·45	59·61	59·84	59·83	59·68
H_{16} . .	16	10·00	10·47	10·21	10·00	10·06	10·18
O_3 . .	48	30·00					30·14
	160	100·00					100·00

We shall prove below that this body is the ethylic ether of an acid possessing the same composition as the leucic acid obtained by STRECKER[*] in acting on leucin with nitrous acid. The two acids are probably isomeric; and we therefore prefer to call the one prepared synthetically *diethoxalic acid*, and the ether above analyzed *ethylic*

---

[*] Ann. der Chem. und Pharm. Bd. lxviii. S. 54.

diethoxalate. The formation of ethylic diethoxalate is explained in the following equations:—

$$\underset{\text{Ethylic oxalate.}}{\left\{\begin{matrix}\mathrm{C\,O\,Eto}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + \underset{\text{Zincethyl.}}{2\mathrm{Zn''\,Et_2}} = \underset{\text{Ethylic zincmonethyl diethoxalate.}}{\left\{\begin{matrix}\mathrm{C\,Et_2\,(O\,Zn''\,Et)}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + \underset{\text{Zincethylo-ethylate.}}{\mathrm{Zn''\,Et\,Eto}};$$

$$\underset{\text{Ethylic zincmonethyl diethoxalate.}}{\left\{\begin{matrix}\mathrm{C\,Et_2\,(O\,Zn''\,Et)}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + 2\mathrm{H_2O} = \underset{\text{Ethylic diethoxalate.}}{\left\{\begin{matrix}\mathrm{C\,Et_2\,Ho}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + \underset{\text{Zinc hydrate.}}{\mathrm{Zn''\,Ho_2}} + \underset{\text{Ethylic hydride.}}{\mathrm{Et\,H}}.$$

The first of these equations expresses the action of zincethyl upon ethylic oxalate, by which ethylic zincmonethyl diethoxalate is formed*. The second shows the action of water upon this compound, by which the zincmonethyl ($\mathrm{Zn\,C_2\,H_5}$) becomes replaced by hydrogen†. Although we have not been able to isolate the body ethylic zincmonethyl diethoxalate from the other product of this decomposition, yet we have proved its existence by forming it synthetically, as described below.

Ethylic diethoxalate is a colourless, transparent, and somewhat oily liquid, possessing a peculiar and penetrating ethereal odour, and a sharp taste. It is insoluble in water, but readily soluble in alcohol or ether. Its specific gravity is ·9613 at 18°·7 C.; it boils at 175° C. and distils unchanged. Two determinations of the specific gravity of its vapour gave the following results:—

	I.	II.
Weight of ethylic diethoxalate	·3723 grm.	·1622 grm.
Observed volume of vapour	100·0 cub. centims.	46·17 cub. centims.
Temperature of bath	202° C.	205° C.
Difference of heights of mercury inside and outside tube	59·00 millims.	119 millims.
Height of oil-column reduced to millims. mercury	19·0 ,,	17·9 ,,
Height of barometer	763 ,,	775 ,,
Specific gravity of vapour	5·241	5·23

The formula

$$\mathrm{C_2}\left\{\begin{array}{l}\mathrm{(C_2\,H_5)_2}\\ \mathrm{O\;H}\\ \hline \mathrm{O}\\ \mathrm{O\,C_2\,H_5}\end{array}\right. \text{ or } \left\{\begin{matrix}\mathrm{C\,Et_2\,Ho}\\ \mathrm{C\,O\,Eto}\end{matrix}\right. = 2 \text{ vols.}$$

requires the number 5·528. We have remarked on this and other similar discrepancies below.

---

[*] This interpretation of the reaction was first proposed by Butlerow (Bul. Soc. Chimique, 1864, p. 116); and we have since confirmed it by the synthetical production of ethylic zincmonethyl diethoxalate, as described below.

[†] The final result of this reaction is exactly homologous with the production of glycollic acid by the action of nascent hydrogen upon oxalic acid, described by Schulze (Ann. de Chim. et de Phys. t. lxvii. p. 366),

$$\underset{\text{Oxalic acid.}}{\left\{\begin{matrix}\mathrm{C\,O\,Ho}\\ \mathrm{C\,O\,Ho}\end{matrix}\right.} + \mathrm{H_4} = \underset{\text{Glycollic acid.}}{\left\{\begin{matrix}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{matrix}\right.} + \mathrm{H_2O}.$$

When zincethyl is added to ethylic diethoxalate previously cooled in a freezing-mixture, each drop of the zinc compound, as it comes into contact with the ether, hisses like phosphoric anhydride when dropped into water. Torrents of ethylic hydride are evolved, and the mixture finally solidifies to a white tenacious mass which fuses on the application of heat, and does not distil below 100° C., at about which temperature a violent action sets in; a great quantity of gas is evolved, and the residue solidifies to a pitchlike mass, which on treatment with water and subsequent distillation yields about one-fourth of the ethylic diethoxalate employed. If the above-mentioned white mass, instead of being heated, be mixed with water, it effervesces strongly, zinc hydrate is formed, and pure ethylic diethoxalate separates in quantity nearly equal to that originally employed.

In a quantitative experiment 12·93 grms. of zincethyl were treated with ethylic diethoxalate, excess being avoided; 15·67 grms. of ethylic diethoxalate were required to saturate the above quantity of zincethyl, and the weight of ethylic hydride evolved, which was carefully determined, amounted to 3·08 grms. These numbers closely agree with those deduced from the following equation:—

$$\underset{\substack{\text{Ethylic}\\\text{diethoxalate.}}}{\begin{cases}\text{C Et}_2\,\text{Ho}\\\text{C O Eto}\end{cases}} + \text{Zn}''\,\text{Et}_2 = \underset{\substack{\text{Ethylic zincmonethyl}\\\text{diethoxalate.}}}{\begin{cases}\text{C Et}_2\,(\text{O Zn}''\,\text{Et})\\\text{C O Eto}\end{cases}} + \text{Et H},$$

as seen from the annexed comparison:—

	Theoretical.	Experimental.
Ethylic diethoxalate required to decompose 12·93 grms. of zincethyl	15·55 grms.	15·67 grms.
Weight of ethylic hydride evolved . . .	3·04 grms.	3·08 grms.

Ethylic zincmonethyl diethoxalate is a colourless viscous solid, soluble in ether, but apparently incapable of crystallization. It absorbs oxygen with avidity, and in contact with water effervesces strongly, reproducing ethylic diethoxalate, according to the following equation:—

$$\underset{\substack{\text{Ethylic zincmonethyl}\\\text{diethoxalate.}}}{\begin{cases}\text{C Et}_2(\text{O Zn}''\,\text{Et})\\\text{C O Eto}\end{cases}} + 2\,\text{H}_2\text{O} = \underset{\substack{\text{Ethylic}\\\text{diethoxalate.}}}{\begin{cases}\text{C Et}_2\,\text{Ho}\\\text{C O Eto}\end{cases}} + \text{Et H} + \text{Zn}''\,\text{Ho}_2.$$

Ethylic zincmonethyl diethoxalate combines energetically with iodine, an ethereal solution of the latter added to it is almost instantaneously decolorized, and a large quantity of ethylic iodide is produced. In continuation of the above quantitative experiment the following results were obtained.

The product of the action of 12·93 grms. of zincethyl upon 15·67 grms. of ethylic diethoxalate decolorized an ethereal solution containing 23·75 grms. of iodine, the quantity required by the following equation being 25·04 grms.

$$\underset{\text{Ethylic zincmonethyl diethoxalate.}}{2\left\{\begin{matrix}\mathrm{C\,Et_2\,(O\,Zn''Et)}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + \mathrm{I_4} = \underset{\text{Ethylic zincodiethoxalate.}}{\begin{matrix}\left\{\begin{matrix}\mathrm{C\,O\,Eto}\\ \mathrm{C\,Et_2\,O}\end{matrix}\right.\\ \left\{\begin{matrix}\mathrm{C\,Et_2\,O}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.\end{matrix}\mathrm{Zn''}} + \mathrm{Zn''\,I_2} + 2\mathrm{Et\,I}.$$

It was obviously impossible to collect in a state of purity the ethylic iodide thus set at liberty without considerable loss; but the quantity of the pure iodide actually obtained was 12 grms. The above equation requires 14·6 grms.

On the removal of ether and ethylic iodide, the mixture of ethylic zincodiethoxalate and zincic iodide forms a transparent gummy mass easily soluble in ether, carbonic disulphide, or caoutchoucin, but totally incapable of crystallizing from any of its solutions. All our attempts to separate these bodies have hitherto proved abortive; and it is by no means improbable that they are chemically combined.

The existence of monad organo-zinc radicals, such as zincmonethyl, receives further support from the slow action of oxygen upon zincethyl, which clearly shows that there are two distinct stages in the process of oxidation. These stages have indeed already been indicated by one of us in describing the reactions of this body*. When a current of dry oxygen is made to pass through an ethereal solution of zincethyl, dense white fumes continue to fill the atmosphere of the vessel, until about one-half of the total quantity of oxygen necessary for the complete oxidation of the zincethyl has been taken up. Then the white fumes entirely cease, showing the absence of free zincethyl, and at the same moment the liquid, which up to that time had remained perfectly transparent, begins to deposit a copious white precipitate, and the latter continues to increase until the remaining half of the oxygen is absorbed. If the process of oxidation be arrested when the white fumes cease to be formed, the product effervesces violently when mixed with water, owing to the escape of ethylic hydride; but when the oxidation is completed, the white solid mass produced consists chiefly of zincethylate, and does not in the slightest degree effervesce in contact with water. The two stages of this reaction depend essentially upon the successive linking of the zinc with the two atoms of ethyl by means of dyad oxygen. The first stage of oxidation is expressed by the following equation,

$$\underset{\text{Zincethyl.}}{\mathrm{Zn''\,Et_2}} + \mathrm{O} = \underset{\text{Zincethylo-ethylate.}}{\mathrm{Zn''\,Et\,Eto}}.$$

The zincethylo-ethylate thus formed is perfectly soluble in ether, and is instantly decomposed by water, according to the following equation,

$$\underset{\text{Zincethylo-ethylate.}}{\mathrm{Zn''\,Et\,Eto}} + 2\mathrm{H_2O} = \underset{\text{Zinc hydrate.}}{\mathrm{Zn''\,Ho_2}} + \underset{\text{Alcohol.}}{\left.\begin{matrix}\mathrm{Et}\\ \mathrm{H}\end{matrix}\right\}\mathrm{O}} + \underset{\text{Ethylic hydride.}}{\left.\begin{matrix}\mathrm{Et}\\ \mathrm{H}\end{matrix}\right\}}.$$

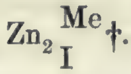
Treated with dry oxygen, zincethylo-ethylate in ethereal solution absorbs a second atom of that element; and it is this further absorption that constitutes the second stage above referred to, resulting in the production of zincic ethylate,

---

* Philosophical Transactions, 1855, p. 268.

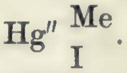
$$Zn'' \, Et \, Eto + O = Zn'' \, Eto_2.$$

Wanklyn* was the first clearly to point out the probable existence of zincmonethyl, or rather its homologue zincmonomethyl, indicating at the same time its radical function, when he ascribed to the crystalline compound obtained in the preparation of zincmethyl the formula



$$Zn_2 \begin{matrix} Me \\ I \end{matrix} \dagger.$$

In the same memoir he also represented this compound as the analogue of mercuric methiodide,



$$Hg'' \begin{matrix} Me \\ I \end{matrix}.$$

Butlerow‡ has also prominently drawn attention to this behaviour of organic zinc compounds, and has succeeded in obtaining zincmethylo-methylate,

$$Zn'' \, Me \, Meo$$

in a condition approaching to purity by passing a stream of dry air through a solution of zincmethyl in methylic iodide. Butlerow's success in obtaining this body, and his failure in converting it into zincmethylate, are both probably due to the comparative insolubility of zincmethylo-methylate in methylic iodide, owing to which the first product of oxidation was to a great extent protected from the further action of oxygen. When, however, ether is used as the solvent in the case of zincethyl, the oxidized product remains in solution till the first stage is passed, after which zincethylate is gradually precipitated until the second stage is completed. Indeed, as has been shown in the memoir above referred to (Philosophical Transactions, 1855, p. 268), the oxidation, instead of stopping at the first stage, proceeds even somewhat further than the second, and the final product formed does not possess a composition in any degree approaching that which Butlerow asserts it to have. This is evident from the following numbers, and from the circumstance that it does not effervesce in the slightest degree when mixed with water:—

	Percentage composition according to Butlerow's formula, $Zn'' \begin{matrix} C_2H_5 \\ OC_2H_5 \end{matrix}$.	Percentage composition according to mean of analyses §.
C	34·53	25·43
H	7·20	5·32
Zn	46·76	42·04
O	11·51	27·21
	100·00	100·00

When ethylic diethoxalate is treated with solution of baric hydrate, it gradually dissolves, even in the cold; on heating the solution in a water-bath, a liquid having the properties of alcohol distils off; and on separating the excess of baryta by carbonic acid and filtration, the solution yields on evaporation a crystallizable barium-salt, which after drying at 100° C., gave on analysis the following numbers:—

---

* Journ. Chem. Soc. 1861, p. 127.

† Zn=32·5 in this formula.

‡ Bul. Soc. Chimique, 1864, p. 116.

§ Philosophical Transactions, 1855, p. 268.

I. ·3510 grm., burnt with plumbic chromate, gave ·4613 grm. carbonic anhydride and ·1873 grm. water.

II. ·3490 grm. gave ·4580 grm. carbonic anhydride and ·1842 grm. water.

III. ·4545 grm., dissolved in water and precipitated with sulphuric acid, gave ·2618 grm. baric sulphate.

These results agree closely with the formula of baric diethoxalate, as shown in the following comparison:—

$$\left.\begin{matrix}\left\{\begin{matrix}C\,Et_2\,Ho\\ C\,O\,O\end{matrix}\right.\\ \left\{\begin{matrix}C\,O\,O\\ C\,Et_2\,Ho\end{matrix}\right.\end{matrix}\right. Ba''.$$

	Calculated.		Found.			
			I.	II.	III.	Mean.
C_{12} . .	144	36·09	35·82	35·79	——	35·81
H_{22} . .	22	5·51	5·88	5·86	——	5·87
Ba . .	137	34·33	——	——	33·87	33·87
O_6 . .	96	24·07	——	——	——	24·45
	399	100·00				100·00

Baric diethoxalate is very soluble, even in cold water; when its boiling solution is precipitated with excess of dilute sulphuric acid and the baric sulphate removed by filtration, ether readily extracts diethoxalic acid from the cooled filtrate. On evaporating the ethereal solution, the acid crystallizes in splendid prisms, which, after drying *in vacuo*, gave the following analytical results:—

I. ·3265 grm. gave ·6510 grm. carbonic anhydride and ·2720 grm. water.

II. ·2510 grm. gave ·5006 grm. carbonic anhydride and ·2083 grm. water.

These numbers correspond well with those calculated from the formula

$$C_6\,H_{12}\,O_3 \text{ or } \left\{\begin{matrix}C\,Et_2\,Ho\\ C\,O\,Ho\end{matrix}\right. :$$

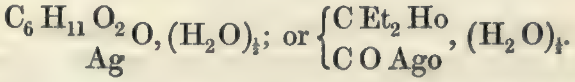
	Calculated.		Found.		
			I.	II.	Mean.
C_6 . .	72	54·54	54·35	54·38	54·37
H_{12} .	12	9·09	9·25	9·22	9·24
O_3 . .	48	36·37			36·39
	132	100·00			100·00

Diethoxalic acid is very soluble in alcohol or ether, and somewhat less so in water. By the spontaneous evaporation of its aqueous solution, it crystallizes in minute prismatic needles; but if a small quantity of dilute sulphuric acid be added to the solution, the crystals are deposited in magnificent anorthic prisms, which frequently attain a length of 1 inch and a thickness of ¼ inch.

Diethoxalic acid is greasy to the touch, like stearic acid; it fuses at 74°·5 C., and slowly sublimes at the same temperature, but is decomposed before reaching its boiling-point. It has a sour taste, reddens litmus strongly, and expels carbonic acid from bases. It forms an extensive series of salts, which are all soluble in water. In addition to the barium-salt described above, we have examined the silver, copper, and zinc salts.

Argentic diethoxalate is readily prepared by boiling an aqueous solution of the acid with excess of argentic carbonate. On filtration and evaporation *in vacuo*, the salt crystallizes in brilliant needles, radiating from centres standing up freely from the capsule, and containing half a molecule of water, which is not expelled at 100° C.

Submitted to analysis this salt gave the following numbers, indicating the formula



$$\left.\begin{matrix}C_6H_{11}O_2\\ Ag\end{matrix}\right.O,(H_2O)_{\frac{1}{2}};\ \text{or}\ \left\{\begin{matrix}C\,Et_2\,Ho\\ C\,O\,Ago\end{matrix}\right.,(H_2O)_{\frac{1}{2}}.$$

·5035 grm. gave ·5283 grm. carbonic anhydride, ·2248 grm. water, and ·2158 grm. silver.

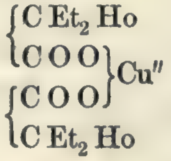
	Calculated.		Found.
C_6	72	29·03	28·62
H_{12}	12	4·84	4·96
$O_{3\frac{1}{2}}$	56	22·58	——
Ag	108	43·55	42·86
	248	100·00	

Cupric diethoxalate is obtained by mixing atomic proportions of baric diethoxalate with cupric sulphate, filtering, and evaporating to dryness. The salt does not crystallize, but dries down to a green gum-like mass, which becomes nearly white on being reduced to powder. Submitted to analysis, it yielded the following results:—

I. ·3380 grm., burnt with cupric oxide, gave ·5460 grm. carbonic anhydride and ·2120 grm. water.

II. ·2090 grm. gave ·0505 grm. cupric oxide.

These numbers agree with the formula



$$\left.\begin{matrix}\left\{\begin{matrix}C\,Et_2\,Ho\\ C\,O\,O\end{matrix}\right.\\ \left\{\begin{matrix}C\,O\,O\\ C\,Et_2\,Ho\end{matrix}\right.\end{matrix}\right\}Cu''$$

	Calculated.		Found.	
			I.	II.
C_{12} . . .	144	44·24	44·06	——
H_{22} . . .	22	6·76	6·96	——
Cu . . .	63·5	19·51	——	19·35
O_6 . . .	96	29·49	——	——
	325·5	100·00		

Zincic diethoxalate crystallizes in nacreous scales, which are sparingly soluble in water and in alcohol. Two determinations of the solubility of this salt in water at 16° C. gave the following results:—

I. One part of the salt dissolved in 291 parts of water.

II. One part of the salt dissolved in 312 parts of water.

Its solubility in boiling water is not much greater. Although so difficultly soluble in pure water, it dissolves very readily in a solution of zincic iodide.

The method of producing ethylic diethoxalate above described involves the previous preparation of considerable quantities of zincethyl; but we have found that the process may be much simplified by generating the zincethyl during the reaction, which is effected by gently heating a mixture of granulated zinc, ethylic iodide, and ethylic oxalate for several hours. After long experience in the production of this and other homologous compounds described below, we have found the following process for the preparation of ethylic diethoxalate to give a maximum product.

600 grammes of a mixture consisting of one molecule of ethylic oxalate and two of ethylic iodide, were placed in a capacious flask with such a quantity of well-dried granulated zinc that the latter rose above the surface of the liquid. An inverted Liebig's condenser was attached to the flask. It is preferable to use zinc which has been employed in a previous operation, as it not only acts with greater rapidity, but also at a much lower temperature. The flask was immersed in water maintained at a temperature of about 30° C. After a period of time which varies in each operation, but which is usually from twelve to twenty-four hours, an energetic action sets in, which must be checked by lowering the temperature of the water-bath. The reaction once commenced is usually completed in from twelve to eighteen hours, the temperature of the water-bath being maintained at about 30° C. until it is nearly concluded, when it may be raised to 100° C. The operation may be regarded as complete when the hot liquid assumes the consistency of honey, and solidifies to a more or less crystalline mass on cooling, although a considerable quantity of the mixed ethers is still unacted upon. Water being now gradually added until it equals three times the volume of the crystalline mass, with which it must be well mixed by agitation, a copious effervescence takes place; zincic oxalate and oxide are formed in abundance, whilst, on the application of the heat of an oil-bath, alcohol, accompanied by ethylic diethoxalate, distils over together with the ethylic iodide that has not been acted upon. This distillate is then treated in exactly the same manner as that already described for the separation and purification of

ethylic diethoxalate prepared by means of zincethyl. In the operation above mentioned with 600 grammes of the mixed ethylic iodide and oxalate, 86 grammes of pure ethylic diethoxalate were obtained, the theoretical amount being 105 grammes.

II. *Action of Zinc upon a Mixture of Methylic Iodide and Methylic Oxalate.*

Two atoms of methylic iodide were mixed with one of methylic oxalate, and placed in contact with an excess of granulated zinc at 30° C. in a flask as above described. At the conclusion of the reaction the liquid solidified to a crystalline mass, which, on distillation with water, yielded methylic alcohol possessing an ethereal odour, but from which no ether could be extracted. The residual magma in the flask, consisting of zincic iodide, zincic oxalate, and the zinc salt of a new acid, was separated from the metallic zinc by washing with water. It was then treated with an excess of baric hydrate, and boiled for a considerable time; carbonic anhydride was afterwards passed through the liquid until, on again boiling, the excess of baryta was completely removed. To the filtered solution recently precipitated argentic oxide was added until all iodine was removed. The solution separated from the argentic iodide was again submitted to a current of carbonic anhydride, boiled, and filtered. The resulting liquid, on being evaporated on the water-bath, yielded a salt crystallizing in brilliant needles, possessing the peculiar odour of fresh butter. This salt is very soluble in water and in alcohol, but nearly insoluble in ether, and perfectly neutral to test-papers. On being submitted to analysis, it gave numbers closely corresponding with the formula

$$\begin{array}{l}\left\{\begin{array}{l}\mathrm{C\,Me_2\,Ho}\\ \mathrm{C\,O\,O}\end{array}\right.\\ \left\{\begin{array}{l}\mathrm{C\,O\,O}\\ \mathrm{C\,Me_2\,Ho}\end{array}\right.\end{array}\mathrm{Ba}''.$$

I. ·4318 grm. baric dimethoxalate, heated in a porcelain boat with potassic dichromate in a stream of air and oxygen, the products being afterwards passed over ignited cupric oxide, gave ·4268 grm. carbonic anhydride and ·1624 grm. water.

II. ·3856 grm. gave ·3796 grm. carbonic anhydride and ·1448 grm. water.

III. ·3795 grm. gave ·2574 grm. baric sulphate.

IV. ·4072 grm. gave ·2767 grm. baric sulphate.

	Calculated.		Found.				
			I.	II.	III.	IV.	Mean.
C_8 . . .	96	27·99	26·96*	26·85	——	——	26·91
H_{14} . .	14	4·08	4·18	4·17	——	——	4·18
Ba . .	137	39·93	——	——	39·89	39·95	39·92
O_6 . . .	96	28·00	——	——	——	——	28·99
	343	100·00					100·00

---

* In analyzing barium-salts by this method of combustion, we have almost invariably found a deficiency of about 1 per cent. of carbon, due in all probability to the small quantity of potassic dichromate which can be mixed with the salt in a porcelain boat.

Dimethoxalic acid is obtained from its barium-salt by adding dilute sulphuric acid to a concentrated solution of the latter, and agitating with ether. On allowing the ether to evaporate spontaneously, prismatic crystals of considerable size make their appearance. These yielded on combustion the following results:—

·1895 grm. gave ·3207 grm. carbonic anhydride and ·1334 grm. water.

The formula

$$\begin{cases} \mathrm{C\,Me_2\,Ho} \\ \mathrm{C\,O\,Ho} \end{cases}$$

agrees well with these numbers, as seen from the following comparison:—

	Calculated.		Found.
C_4 . .	48	46·15	46·15
H_8 . .	8	7·69	7·86
O_3 . .	48	46·16	45·99
	104	100·00	100·00

Dimethoxalic acid is a white solid readily crystallizing in beautiful prisms resembling oxalic acid. It fuses at 75°·7 C., volatilizes slowly even at common temperatures, and readily sublimes at 50° C., being deposited on a cool surface in magnificent prisms. It boils at about 212° C., and distils unchanged. Dimethoxalic acid reacts strongly acid, and unites with bases, forming a numerous class of salts, several of which are crystalline. In addition to the barium-salt above mentioned we have examined the silver-salt, which is best formed by adding argentic oxide to the free acid, heating to boiling, and filtering, when the salt is deposited in starlike masses of nacreous scales as the solution cools. On analysis this salt gave numbers closely corresponding with those calculated from the formula

$$\begin{cases} \mathrm{C\,Me_2\,Ho} \\ \mathrm{C\,O\,Ago} \end{cases}.$$

I. ·3883 grm. gave ·3258 grm. carbonic anhydride and ·1207 grm. water.

II. ·3635 grm. gave ·3033 grm. carbonic anhydride, ·1097 grm. water, and ·1862 grm. silver.

III. ·2536 grm. gave ·2144 grm. carbonic anhydride, ·0792 grm. water, and ·1302 grm. silver[*].

IV. ·2617 grm. gave ·1111 grm. metallic silver.

V. ·2467 grm. gave ·1266 grm. metallic silver.

VI. ·3400 grm. gave ·1747 grm. metallic silver.

---

[*] The acid of the salt used for determinations Nos. III. and IV. was prepared by adding zincmethyl to methylic oxalate, and then heating the mixture to 120° C. for several hours in a digester.

	Calculated.		Found.						
			I.	II.	III.	IV.	V.	VI.	Mean.
C_4 .	48	22·75	22·88	22·75	23·05	——	——	——	22·89
H_7 .	7	3·32	3·45	3·35	3·40	——	——	——	3·40
Ag .	108	51·18	——	51·22	51·34	51·26	51·31	51·38	51·30
O_3 .	48	22·75	——	——	——	——	——	——	22·41
	211	100·00							100·00

Attempts to produce ethylic dimethoxalate by digesting the free acid with absolute alcohol at a temperature of 160° C. proved abortive, traces only of the ether being apparently formed. Judging, however, from our subsequent success in obtaining ethylic dimethoxalate as described below, we believe that the methylic ether would probably be obtained by repeatedly agitating with ether the aqueous distillate obtained from the crude product of the original operation, methylic dimethoxalate being evidently like ethylic dimethoxalate, miscible with water in all proportions. Assuming the formation of this ether, its production from the mutual action of zinc, methylic oxalate, and methylic iodide, followed by that of water, would be expressed in the following equations:—

$$\underset{\text{Methylic oxalate.}}{\left\{\begin{array}{l}\mathrm{C\,O\,Meo}\\ \mathrm{C\,O\,Meo}\end{array}\right.} + \mathrm{Zn}''_4 + 4\,\mathrm{Me\,I} = \underset{\text{Methylic zincmonomethyl dimethoxalate.}}{\left\{\begin{array}{l}\mathrm{C\,Me_2\,(O\,Zn''\,Me)}\\ \mathrm{C\,O\,Meo}\end{array}\right.} + \underset{\text{Zincmethylo-methylate.}}{\mathrm{Zn''\,Me\,Meo}} + 2\,\mathrm{Zn''\,I_2}:$$

$$\underset{\text{Methylic zincmonomethyl dimethoxalate.}}{\left\{\begin{array}{l}\mathrm{C\,Me_2\,(O\,Zn''\,Me)}\\ \mathrm{C\,O\,Meo}\end{array}\right.} + 2\,\mathrm{H_2O} = \underset{\text{Methylic dimethoxalate.}}{\left\{\begin{array}{l}\mathrm{C\,Me_2\,Ho}\\ \mathrm{C\,O\,Meo}\end{array}\right.} + \left.\begin{array}{r}\mathrm{Me}\\ \mathrm{H}\end{array}\right\} + \underset{\text{Zincic hydrate.}}{\mathrm{Zn''\,Ho_2}}.$$

Dimethoxalic acid exhibits the same composition as STAEDELER'S acetonic acid, WURTZ'S butylactic acid, and the oxybutyric acid obtained by FRIEDEL and MACHUCA. The relations of these acids to each other will be discussed at the conclusion of this paper.

III. *Action of Zinc upon a Mixture of Ethylic Iodide and Methylic Oxalate.*

This reaction was performed in exactly the same manner as the last. On the addition of water, the product yielded, on subsequent distillation, a considerable quantity of an ethereal body, which distilled over together with the ethylic iodide that had not been acted upon. The addition of water to the distillate effected an approximate separation of the ethereal from the alcoholic portion; the former was then decanted and distilled for the purpose of separating alcohol and ethylic iodide. When the temperature of ebullition rose to 100° C., the liquid left in the retort was placed over calcic chloride for twelve hours, after which it was again submitted to distillation, when its boiling-point almost immediately rose to 165° C. (barom. 758·2 millims.), at which temperature the whole of the remaining liquid passed over. Submitted to analysis, this liquid yielded results closely corresponding to the formula

$$C_7\,H_{14}\,O_3.$$

I. ·2324 grm. gave ·4903 grm. carbonic anhydride and ·2034 grm. water.
II. ·2534 grm. gave ·5354 grm. carbonic anhydride and ·2190 grm. water.

	Calculated.		Found.		
			I.	II.	Mean.
C_7 . .	84	57·54	57·57	57·62	57·59
H_{14} . .	14	9·59	9·72	9·60	9·66
O_3 . .	48	32·87	——	——	32·75
	146	100·00			100·00

The decomposition of this ether by baryta described below, proves it to be the methylic ether of an acid of the same composition as diethoxalic acid, with which it also agrees in its fusing-point. The composition of this ether may therefore be thus expressed,

$$\left\{\begin{matrix} C\,Et_2\,Ho \\ C\,O\,Meo \end{matrix}\right..$$

Methylic diethoxalate is a colourless, transparent, and tolerably mobile liquid, possessing a peculiar ethereal odour, only remotely resembling ethylic diethoxalate. It is very sparingly soluble in water, but readily soluble in alcohol or ether. Its specific gravity is ·9896 at 16°·5 C. It boils at 165° C., and distils unchanged. A determination of its vapour-density gave the following data:—

Weight of methylic diethoxalate	·1968 grm.
Observed volume of vapour	57·3 cub. centims.
Temperature of bath	192° C.
Height of barometer	760 millims.
Difference of heights of mercury inside and outside tube . .	68·5 millims.
Heights of sperm. column reduced to millimetres of mercury .	15·7 millims.

From these numbers the specific gravity was calculated to be 4·84. The above formula, corresponding to two volumes of vapour, requires the number 5·03.

Treated with caustic alkaline bases, this ether is readily decomposed even in the cold, yielding methylic alcohol and a diethoxalate of the base. A quantity of it was thus decomposed with solution of baryta, the excess of base being afterwards removed. It yielded on evaporation a crystalline mass very soluble in water, alcohol, or ether, and which on analysis gave results corresponding with those calculated from the formula of *baric diethoxalate*,

$$\left.\begin{matrix} \left\{\begin{matrix} C\,Et_2\,Ho \\ C\,O\,O \end{matrix}\right. \\ \left\{\begin{matrix} C\,O\,O \\ C\,Et_2\,Ho \end{matrix}\right. \end{matrix}\right. Ba''.$$

I. ·1964 grm. gave ·2538 grm. carbonic anhydride and ·1005 grm. water.
II. ·5202 grm. gave ·3073 grm. baric sulphate.

	Calculated.		Found.	
			I.	II.
C_{12} . .	144	36·09	35·24	—
H_{22} . .	22	5·51	5·69	—
Ba . .	137	34·33	—	34·73
O_6 . .	96	24·07	—	—
	399	100·00		

When this barium-salt in aqueous solution is decomposed with the exact amount of sulphuric acid necessary, the liquid filtered off from the baric sulphate, and evaporated *in vacuo*, the acid crystallizes magnificently. Professor W. Hallows Miller of Cambridge has kindly examined and measured these crystals for us with the following results:—

Anorthic:—

1 0 0, 1 1 0=66° 2′;
1 1 0, 0 1 0=34° 15′; 1 0 0, 0 0 1=76° 40′;
0 0 1, $\bar{1}$ 0 1=29° 4′; 0 1 0, 0 0 1=75° 13′.

Observed forms:—

1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 1 0, $\bar{1}$ 0 1, $\bar{2}$ 0 1.

	Angles. °	′
0 1 0, 0 0 1	75	13
0 0 1, 0 $\bar{1}$ 0	104	47
1 0 0, 0 0 1	76	40
$\bar{1}$ 0 0, 0 0 1	103	20
1 0 0, $\bar{1}$ 0 1	105	44
$\bar{1}$ 0 0, $\bar{1}$ 0 1	74	16
1 0 0, $\bar{2}$ 0 1	128	41
$\bar{1}$ 0 0, $\bar{2}$ 0 1	51	19
0 0 1, $\bar{1}$ 0 1	29	4
$\bar{1}$ 0 1, $\bar{2}$ 0 1	22	56
1 0 0, 0 1 0	100	17
$\bar{1}$ 0 0, 0 1 0	79	43
1 0 0, 1 1 0	66	2
0 1 0, 1 1 0	34	15
0 1 0, $\bar{1}$ 1 0	28	36

	Angles. ° ′
1 0 0, 1 1 0	51 7
0 1 0, $\bar{1}$ 0 1	70 0
0 1 0, $\bar{2}$ 0 1	69 31
1 1 0, 0 0 1	68 19
1 1 0, $\bar{2}$ 0 1	91 52
$\bar{1}$ 1 0, 0 0 1	84 50
$\bar{1}$ 1 0, $\bar{1}$ 0 1	66 16
$\bar{1}$ 1 0, $\bar{2}$ 0 1	54 30

Combinations:—

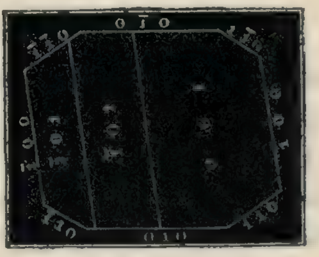
1 0 0, 0 1 0, 0 0 1, 1 1 0
1 0 0, 0 1 0, 0 0 1, $\bar{1}$ 0 1
1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 0 1
1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 1 0
1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 0 1, $\bar{2}$ 0 1
1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 0 1, $\bar{1}$ 1 0
1 0 0, 0 1 0, 0 0 1, 1 1 0, $\bar{1}$ 0 1, $\bar{1}$ 1 0, $\bar{2}$ 0 1.

Cleavage:—

1 0 0, 0 1 0, very perfect and easily obtained.

The optic axes seen in air through the faces of the form 0 1 0 appear to make with one another an angle of about 71°. Denoting by α, β the extremities of radii of the sphere of projection drawn parallel to the directions of the optic axes seen in air through the faces of the form 0 1 0, the arcs joining α, β and the nearest poles of faces are approximately as follows:—

	° ′
0 1 0, α	19 40
0 0 1, α	73 1
1 1 0, α	14 58
$\bar{1}$ 0 0, β	29 54
0 0 1, β	78 51
0 1 0, β	51 28



This acid is readily soluble in ether, alcohol, and water; it is greasy to the touch, and nearly inodorous. It sublimes readily at 50° C., and slowly even at common temperatures, a small quantity of the acid left on a watchglass gradually disappearing, though in other respects it is permanent when exposed to the air. It fuses at 74°·5 C. Submitted to analysis it gave the following numbers:—

I. ·2732 grm. gave ·5432 grm. carbonic anhydride and ·2251 grm. water.

II. ·3477 grm. gave ·6944 grm. carbonic anhydride and ·2867 grm. water.

The formula

$$C_6H_{12}O_3 \text{ or } \begin{cases} C\,Et_2\,Ho \\ C\,O\,Ho \end{cases}$$

represents percentage amounts of carbon and hydrogen agreeing closely with those calculated from the above results.

	Calculated.		Found.		
			I.	II.	Mean.
C_6	72	54·54	54·23	54·47	54·35
H_{12}	12	9·09	9·15	9·16	9·15
O_3	48	36·37	——	——	36·50
	132	100·00			100·00

Argentic diethoxalate was made by adding argentic oxide to a hot solution of the acid. After filtration and evaporation *in vacuo*, it crystallizes in brilliant silky fibres adhering closely to the capsule. These are anhydrous, and are scarcely discoloured by prolonged exposure to a temperature of 100° C. They yielded on analysis numbers closely corresponding with those calculated from the formula

$$C_6H_{11}AgO_3 \text{ or } \begin{cases} C\,Et_2\,Ho \\ C\,O\,Ago \end{cases}$$

I. ·3895 grm. gave ·4258 grm. carbonic anhydride, ·1702 grm. water, and ·1740 grm. metallic silver.

	Calculated.		Found.
C_6	72	30·12	29·82
H_{11}	11	4·60	4·85
Ag	108	45·23	44·67
O_3	48	20·05	——
	239	100·00	

Although the diethoxalic acid obtained by the action of zincethyl upon methylic oxalate possesses the same atomic weight and fusing-point as that prepared by the action of zincethyl upon ethylic oxalate, yet the two acids do not appear to be identical. The silver-salt of the latter crystallizes, as above described (page 318), in brilliant needles radiating from centres standing freely up from the capsule, and containing half a molecule of water, which is not expelled at 100° C. This salt also further differs from that just described by being rapidly discoloured when exposed to the heat of a steam-bath. In a future communication we hope to be able to throw additional light upon this apparent isomerism.

IV. *Action of Zinc upon a Mixture of Ethylic Iodide, Methylic Iodide, and Ethylic Oxalate.*

Having proved in the foregoing reactions the possibility of replacing one atom of oxygen in ethylic oxalate by two atoms of either methyl or ethyl, we thought it desirable to ascertain whether the same replacement could be effected by an atom of each of two different monad alcohol-radicals. We endeavoured to accomplish this by acting with zinc upon a mixture consisting of one atom of ethylic oxalate and one atom each of the methylic and ethylic iodides, by which we hoped to obtain an acid of the following composition,

$$C_5\,H_{10}\,O_3=\left\{\begin{matrix}\text{C Et Me Ho}\\ \text{C O Ho}\end{matrix}\right. .$$

Experiment completely proved the practicability of this reaction; and its result even exceeded our expectations, since not only was the ether corresponding to the above acid formed with the greatest facility, but it was produced almost to the complete exclusion of the ethers of diethoxalic and dimethoxalic acids.

200 grammes of ethylic oxalate were mixed with the proper atomic proportions of methylic iodide and ethylic iodide, and were digested with granulated zinc for several days at a temperature of from 35° to 40° C., until the supernatant liquid became oily, and solidified to a crystalline mass on cooling. Water being now added till effervescence ceased, the whole was submitted to distillation in an oil-bath. With the exception of a small quantity of the mixed ethylic and methylic iodides that had escaped decomposition, the distillate consisted of a homogeneous liquid composed of water, ethylic and methylic alcohols, and an ethereal body, which last was separated by repeated agitation with large volumes of ether and subsequent rectification. In this manner there was obtained a large quantity of a liquid which boiled constantly at 165°·5 C., and yielded on analysis numbers very closely corresponding with the formula

$$C_7\,H_{14}\,O_3=\left\{\begin{matrix}\text{C Et Me Ho}\\ \text{C O Eto}\end{matrix}\right. .$$

I. ·2843 grm. gave ·5990 grm. carbonic anhydride and ·2498 grm. water.

II. ·2936 grm. gave ·6188 grm. carbonic anhydride and ·2584 grm. water.

	Calculated.		Found.		
			I.	II.	Mean.
C_7 . .	84	57·54	57·46	57·48	57·47
H_{14} . .	14	9·59	9·76	9·78	9·77
O_3 . .	48	32·87	——	——	32·76
	146	100·00			100·00

The production of this ether is explained in the following equations:—

$$\underset{\substack{\text{Ethylic}\\ \text{oxalate.}}}{\left\{\begin{matrix}\text{C O Eto}\\ \text{C O Eto}\end{matrix}\right.}+4\,\text{Zn}+2\,\text{Et I}+2\,\text{Me I}=\underset{\substack{\text{Ethylic zincmonomethyl}\\ \text{ethomethoxalate.}}}{\left\{\begin{matrix}\text{C Et Me(O Zn}''\text{Me)}\\ \text{C O Eto}\end{matrix}\right.}+\text{Zn}''\,\text{Et Eto}+2\,\text{Zn}''\,\text{I}_2;$$

$$\underset{\substack{\text{Ethylic zincmonomethyl}\\ \text{ethomethoxalate.}}}{\begin{cases}\text{C Et Me(O Zn}''\text{Me)}\\ \text{C O Eto}\end{cases}}+2\,H_2O=\underset{\substack{\text{Ethylic ethometh-}\\ \text{oxalate.}}}{\begin{cases}\text{C Et Me Ho}\\ \text{C O Eto}\end{cases}}+\text{Me H}+\underset{\substack{\text{Zincic}\\ \text{hydrate.}}}{\text{Zn}''\text{Ho}_2}.$$

A not inconsiderable amount of the ether thus formed in this and in the analogous reactions described above, appears to be decomposed by the zincic hydrate; at all events an appreciable quantity of the zinc-salt of the derived acid is always obtained from the residue left after distillation of the ethereal product.

Ethylic ethomethoxalate, as we propose to name the new ether, is a colourless, transparent and mobile liquid, possessing a penetrating ethereal odour much resembling that of ethylic diethoxalate. It is very soluble in water, alcohol, and ether, and has a specific gravity of ·9768 at 13° C. It boils at 165°·5 C.; and a determination of its vapour-density gave the following results:—

Weight of ethylic ethomethoxalate	·1614 grm.
Observed volume of vapour	48·52 cub. centims.
Temperature of bath	188° C.
Height of barometer	758 millims.
Difference of heights of mercury inside and outside tube . .	113·5 millims.
Height of spermaceti column reduced to millimetres of mercury	15·7 millims.

Calculated from these data the specific gravity is 4·98, the theoretical number for a two-volume vapour of the above formula being 5·04.

Ethylic ethomethoxalate is readily decomposed even by aqueous solutions of the alkalies and of baryta, yielding alcohol and a salt of the base. By this means baric ethomethoxalate was prepared. This salt crystallizes from an aqueous solution as a beautiful radiated mass of silky lustre, very easily soluble in water.

Submitted to analysis it gave the following results:—

I. ·3422 grm. gave ·4032 grm. carbonic anhydride and ·1611 grm. water.

II. ·4678 grm. gave on analysis ·2932 grm. baric sulphate.

These numbers agree with the formula

$$C_{10}H_{18}BaO_6,\ \text{or}\ \left.\begin{matrix}\begin{cases}\text{C Et Me Ho}\\ \text{C O O}\end{cases}\\ \begin{cases}\text{C O O}\\ \text{C Et Me Ho}\end{cases}\end{matrix}\right.\text{Ba}'',$$

as seen from the following comparison:—

	Calculated.		Found.	
			I.	II.
C_{10} . .	120	32·35	32·13	——
H_{18} . .	18	4·85	5·23	——
Ba . .	137	36·93	——	36·85
O_6 . .	96	25·87	——	——
	371	100·00		

By exactly decomposing this salt with dilute sulphuric acid and evaporating the filtrate, first in a retort and afterwards *in vacuo*, *ethomethoxalic acid* was obtained as a splendid white crystalline mass, fusing at 63° C., subliming readily at 100° C., and condensing in magnificent star-like groups upon a cold surface. It boils, with decomposition, at 190° C. Ethomethoxalic acid is very readily soluble in ether, alcohol, or water; small fragments of it thrown upon water rotate like camphor whilst dissolving. These solutions react powerfully acid, and readily decompose carbonates.

The analysis of this acid gave the following results:—

I. ·2203 grm. gave ·4126 grm. carbonic anhydride and ·1715 grm. water.

II. ·1744 grm. gave ·3282 grm. carbonic anhydride and ·1389 grm. water.

These numbers correspond with the formula

$$C_5\,H_{10}\,O_3,\ \text{or}\ \left\{\begin{matrix}\text{C Et Me Ho}\\ \text{C O Ho}\end{matrix}\right. :$$

	Calculated.		Found.		
			I.	II.	Mean.
C_5 . . .	60	50·85	51·08	51·32	51·20
H_{10} . . .	10	8·47	8·65	8·85	8·75
O_3 . . .	48	40·68	——	——	——
	118	100·00			

Argentic ethomethoxalate was prepared by treating the free acid dissolved in water with argentic carbonate. The salt crystallizes in splendid mammillated masses half an inch in diameter, which are tolerably soluble in water. It gave on analysis the following numbers:—

·2509 grm. gave ·2449 grm. carbonic anhydride, ·0944 grm. water, and ·1206 grm. metallic silver.

These results agree with the formula

$$C_5\,H_9\,Ag\,O_3,\ \text{or}\ \left\{\begin{matrix}\text{C Et Me Ho}\\ \text{C O Ago}\end{matrix}\right. :$$

	Calculated.		Found.
C_5 . .	60	26·67	26·62
H_9 . .	9	4·00	4·18
Ag . .	108	48·00	48·06
O_3 . .	48	21·33	——
	225	100·00	

V. *Action of Zinc upon a Mixture of Amylic Iodide and Ethylic Oxalate.*

When a mixture of equivalent proportions of ethylic oxalate and amylic iodide is digested with granulated zinc at 70° C., the zinc is gradually dissolved, while much amylic hydride and amylene are given off. The mixture finally assumes a viscous or semisolid condition, and when treated with water produces a further quantity of amylic hydride, which distils off at a gentle heat. On the subsequent application of a higher temperature, water accompanied by amylic alcohol, amylic iodide, and an ethereal liquid distil over, the three latter forming a mixture the separation of which into its component parts presents rather formidable difficulties. After drying with calcic chloride, the oily mixture begins to boil at about 132° C.; the product first passing over consists principally of amylic alcohol mixed with amylic iodide. Afterwards the thermometer rapidly rises to 200° C., between which temperature and 205° C. a considerable section of the remaining liquid, which we will call A, passes over. There then occurs a further rapid rise of temperature until the thermometer remains stationary between 222° and 226° C. The section collected between these points we will call B. Finally, the temperature rises to 260° to 264°, between which points the remaining liquid (C) passes over. By repeated fractional distillation, the larger portion of the section A was obtained at the nearly fixed boiling-point of 203° C. This liquid was submitted to analysis, and yielded the following numbers:—

I. ·2090 grm. gave ·4727 grm. carbonic anhydride and ·1990 grm. water.
II. ·2828 grm. gave ·6425 grm. carbonic anhydride and ·2682 grm. water.

These numbers coincide nearly with the formula

$$C_9\,H_{18}\,O_3,$$

which, interpreted by further results detailed below, resolves itself into

$$\left\{\begin{matrix}C\,Ay\,H\,Ho\\ C\,O\,Eto\end{matrix}\right.:$$

	Calculated.		Found.		
			I.	II.	Mean.
C_9 . . .	108	62·07	61·68	61·96	61·82
H_{18} . . .	18	10·34	10·58	10·54	10·56
O_3 . . .	48	27·59	——	——	——
	174	100·00			

The ethereal body with the lowest boiling-point produced in this reaction is therefore *ethylic amylhydroxalate*, or ethylic oxalate in which one atom of oxygen is replaced by one atom of amyl and one of hydrogen. This body also stands in very close relation to ethylic lactate; for if the atom of methyl in ethylic lactate were replaced by amyl, ethylic amylhydroxalate would be produced,

$$\left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Eto\end{matrix}\right. \qquad\qquad \left\{\begin{matrix}C\,Ay\,H\,Ho\\ C\,O\,Eto\end{matrix}\right..$$

Ethylic lactate. Ethylic amylhydroxalate.

The two stages in the production of ethylic amylhydroxalate are explained in the following equations:—

$$\underset{\text{Ethylic oxalate.}}{\begin{cases}\mathrm{C\,O\,Eto}\\ \mathrm{C\,O\,Eto}\end{cases}}+\mathrm{Zn_5}+4\,\mathrm{Ay\,I}=\begin{cases}\mathrm{C\,Ay(Zn''\,Ay)(O\,Zn''\,Ay)}\\ \mathrm{C\,O\,Eto}\end{cases}+\underset{\text{Zincic amylo-ethylate.}}{\mathrm{Zn''Ay\,Eto}}+2\,\mathrm{Zn''\,I_2}:$$

$$\begin{cases}\mathrm{C\,Ay(Zn''\,Ay)(O\,Zn''\,Ay)}\\ \mathrm{C\,O\,Eto}\end{cases}+4\,\mathrm{H_2O}=\underset{\text{Ethylic amylhydroxalate.}}{\begin{cases}\mathrm{C\,Ay\,H\,Ho}\\ \mathrm{C\,O\,Eto}\end{cases}}+\underset{\text{Zincic hydrate.}}{2\,\mathrm{Zn''\,Ho_2}}+\underset{\text{Amylic hydride.}}{\mathrm{Ay\,H}}+\underset{\text{Amylic alcohol.}}{\mathrm{Ay\,Ho}}.$$

We have not attempted to give a name to the body from which ethylic amylhydroxalate is directly produced by the action of water, as shown in the last of the foregoing equations. The resources of chemical nomenclature, already too severely taxed, would scarcely be able to elaborate a rational name for this body, which consists of ethylic oxalate wherein an atom of oxygen is replaced half by amyl and half by zincmonamyl, whilst a second atom of zincmonamyl is substituted for an atom of ethyl.

Ethylic amylhydroxalate is a somewhat oily, transparent, and slightly straw-coloured liquid of specific gravity ·9449 at 13° C., possessing a pleasant aromatic odour and burning taste. It boils at 203° C.; and a determination of its vapour-density gave the following results:—

Weight of ethylic amylhydroxalate	·1662 grm.
Observed volume of vapour	49·04 cub. centims.
Temperature of bath	230° C.
Height of barometer	766·5 millims.
Difference of heights of mercury inside and outside tube	113 millims.
Height of spermaceti column reduced to millimetres of mercury	16·5 millims.

From these data the specific gravity was calculated to be 5·47, the above formula requiring 6·0. To this discrepancy we shall refer again presently.

Section B of the oily liquid, after careful rectification, gave a product boiling at 224–225°, and yielded on analysis the following results:—

I. ·2858 grm. gave ·6787 grm. carbonic anhydride and ·2803 grm. water.
II. ·3508 grm. gave ·8357 grm. carbonic anhydride and ·3484 grm. water.
III. ·4960 grm. gave 1·1778 grm. carbonic anhydride and ·4862 grm. water.

The percentage numbers calculated from the foregoing agree with the formula

$$\mathrm{C_{11}\,H_{22}\,O_3},$$

as seen from the following comparison.

	Calculated.		Found.			
			I.	II.	III.	Mean.
C_{11} . .	132	65·34	64·77	64·97	64·72	64·82
H_{22} . .	22	10·89	10·90	11·04	10·89	10·94
O_3 . .	48	23·77	——	——	——	——
	202	100·00				

The above formula might be interpreted as that of *ethylic amylethoxalate*, the rational formula of which would be

$$\left\{\begin{matrix}\text{C Ay Et Ho}\\ \text{C O Eto}\end{matrix}\right. .$$

We were at first inclined to regard this as the actual constitution of the new ether, believing it to be possible that ethylic oxalate and amylic iodide mutually decomposed each other, producing a mixture of amylic and ethylic oxalates with the amylic and ethylic iodides; an analogous decomposition of mixed ethereal salts of oxygen acids has been recently noticed; but the test of experiment obliged us to abandon this view of the reaction. We found, it is true, a remarkable depression of temperature, amounting to 9°·3 C. on mixing one atom of ethylic oxalate with one of amylic iodide; but on submitting the mixture to distillation, the thermometer rose to the boiling-point of amylic iodide (147°) before ebullition commenced, thus showing that none of the much more volatile ethylic iodide had been formed. No transfer of radicals therefore takes place when ethylic oxalate is heated with amylic iodide; and consequently no zincethyl can be formed when this mixture is acted on by zinc. We therefore prefer to view the ether now under consideration as ethylic ethyl-amylhydroxalate, analogous in constitution to WURTZ's ethylic ethyl-lactate[*].

$$\underset{\text{Ethylic ethyl-lactate.}}{\left\{\begin{matrix}\text{C Me H Eto}\\ \text{C O Eto}\end{matrix}\right. .} \qquad \underset{\text{Ethylic ethyl-amylhydroxalate.}}{\left\{\begin{matrix}\text{C Ay H Eto}\\ \text{C O Eto}\end{matrix}\right. .}$$

On this view the following equations represent the formation of this ether:—

$$\underset{\substack{\text{Ethylic}\\ \text{oxalate.}}}{\left\{\begin{matrix}\text{C O Eto}\\ \text{C O Eto}\end{matrix}\right.} + \text{Zn}''_4 + \underset{\substack{\text{Amylic}\\ \text{iodide.}}}{4\,\text{Ay I}} = \left\{\begin{matrix}\text{C Ay(Zn}''\text{ Ay)Eto}\\ \text{C O Eto}\end{matrix}\right. + \underset{\substack{\text{Zincic amylo-}\\ \text{amylate.}}}{\text{Zn}''\text{ Ay Ayo}} + 2\,\text{Zn}''\,\text{I}_2:$$

$$\left\{\begin{matrix}\text{C Ay(Zn}''\text{ Ay)Eto}\\ \text{C O Eto}\end{matrix}\right. + 2\,\text{H}_2\text{O} = \underset{\substack{\text{Ethylic ethyl-}\\ \text{amylhydroxalate.}}}{\left\{\begin{matrix}\text{C Ay H Eto}\\ \text{C O Eto}\end{matrix}\right.} + \underset{\substack{\text{Amylic}\\ \text{hydride.}}}{\text{Ay H}} + \underset{\substack{\text{Zincic}\\ \text{hydrate.}}}{\text{Zn}''\,\text{Ho}_2}.$$

---

[*] It deserves to be mentioned that the identity of boiling-point between this ether and its isomer amylic diethoxalate described below does not favour this view, since a comparison of the boiling-points of ethylic ethyl-lactate with that of ethylic ethomethoxalate and methylic diethoxalate, its isomers, shows that the substitution of ethyl for the hydrogen of hydroxyl is attended with a depression of the boiling-point equal to 8°·5 C., the percentage composition of the compound remaining constant.

Ethylic ethyl-amylhydroxalate is a straw-coloured oily liquid, possessing an aromatic but somewhat amylic odour and a burning taste. Its specific gravity was found to be ·9399 at 13° C. It boils between 224° and 225° C. A determination of the specific gravity of its vapour by Gay-Lussac's method gave the following numbers:—

Weight of ethylic ethyl-amylhydroxalate	·1729 grm.
Observed volume of vapour	46·57 cub. centims.
Temperature of bath	261° C.
Height of barometer	768 millims.
Difference of heights of mercury inside and outside tube . .	110 millims.
Height of spermaceti column reduced to millims. of mercury	16·5 millims.

These numbers give the density 6·29, whilst the above formula requires 6·92.

Section C of the oily product, boiling about 262° C., was next submitted to investigation. It gave on analysis the annexed results:—

I. ·2400 grm. gave ·5977 grm. carbonic anhydride and ·2479 grm. water.

II. ·2032 grm. gave ·5046 grm. carbonic anhydride and ·2109 grm. water.

Translated into percentage numbers, these data afford the following comparison with those calculated from the formula

$$C_{14}H_{28}O_3, \text{ or } \left\{\begin{matrix}\text{C Ay}_2\text{ Ho}\\ \text{C O Eto}\end{matrix}\right.;$$

	Calculated.		Found.		
			I.	II.	Mean.
C_{14} . . .	168	68·85	67·92	67·73	67·83
H_{28} . . .	28	11·47	11·48	11·53	11·50
O_3 . . .	48	19·68	——	——	——
	244	100·00			

The body is therefore *ethylic diamyloxalate*, the normal homologue of ethylic diethoxalate, as is seen from the following comparison:—

$$\left\{\begin{matrix}\text{C Et}_2\text{ Ho}\\ \text{C O Eto}\end{matrix}\right. \qquad \left\{\begin{matrix}\text{C Ay}_2\text{ Ho}\\ \text{C O Eto}\end{matrix}\right..$$

Ethylic diethoxalate. Ethylic diamyloxalate.

The production of ethylic diamyloxalate is explained by the following equations:—

$$\left\{\begin{matrix}\text{C O Eto}\\ \text{C O Eto}\end{matrix}\right. + \text{Zn}_4'' + 4\,\text{Ay I} = \left\{\begin{matrix}\text{C Ay}_2(\text{O Zn}''\text{ Ay})\\ \text{C O Eto}\end{matrix}\right. + \text{Zn}''\text{ Ay Eto} + 2\,\text{Zn}''\text{ I}_2;$$

Ethylic oxalate. Ethylic zincmonamyl-diamyloxalate. Zincic amylo-ethylate.

$$\left\{\begin{matrix}\text{C Ay}_2(\text{O Zn}''\text{ Ay})\\ \text{C O Eto}\end{matrix}\right. + 2\,\text{H}_2\text{O} = \left\{\begin{matrix}\text{C Ay}_2\text{ Ho}\\ \text{C O Eto}\end{matrix}\right. + \text{Ay H} + \text{Zn}''\text{ Ho}_2.$$

Ethylic zincmonamyl-diamyloxalate. Ethylic diamyloxalate. Amylic hydride. Zincic hydrate.

Ethylic diamyloxalate closely resembles the two foregoing ethers in its appearance and properties. It is, however, a thicker oil, and flows less readily, and has the lowest specific gravity of any ether belonging to this series, its density at 13° C. being only ·9137. The following comparison of the specific gravities of all the ethers of this series shows that they generally increase inversely as their atomic weights:—

	Formula.	Sp. gr.	Temp. °	Observer.
Ethylic lactate	$C_5 H_{10} O_3$	1·042	13	WURTZ & FRIEDEL.
Ethylic dimethoxalate	$C_6 H_{12} O_3$	0·9931	13	F. & D.
Ethylic ethyl-lactate	$C_7 H_{14} O_3$	0·9203	0	WURTZ.
Ethylic ethomethoxalate	$C_7 H_{14} O_3$	0·9768	13	F. & D.
Methylic diethoxalate	$C_7 H_{14} O_3$	0·9896	16·5	„
Ethylic diethoxalate	$C_8 H_{16} O_3$	0·9613	18·7	„
Ethylic amylhydroxalate	$C_9 H_{18} O_3$	0·9449	13	„
Ethylic ethyl-amylhydroxalate	$C_{11} H_{22} O_3$	0·9399	13	„
Amylic diethoxalate	$C_{11} H_{22} O_3$	0·9322	13	„
Ethylic diamyloxalate	$C_{14} H_{28} O_3$	0·9137	13	„

Ethylic diamyloxalate boils at about 262°, and distils with little or no change. A determination of the specific gravity of its vapour gave the following numbers:—

Weight of ethylic diamyloxalate	·2043 grm.
Observed volume of vapour	56·78 cub. centims.
Temperature of bath	273° C.
Height of barometer	769 millims.
Difference of heights of mercury inside and outside tube	70 millims.
Height of spermaceti column reduced to millims. of mercury	14 millims.

From these data the specific gravity 5·9 was deduced, whilst the above formula requires 8·4. The investigation of these ethers has revealed a tendency to dissociation, increasing with the weight of the atoms replacing the atom of oxygen in ethylic oxalate. Thus, beginning with ethylic lactate, which has the normal vapour-density, we find a gradual divergence culminating in ethylic diamyloxalate, as seen in the following series of numbers:—

Name.	Formula.	Vapour-densities.		Observer.
		Calculated.	Found.	
Ethylic lactate	$C_5 H_{10} O_3$	4·07	4·14	WURTZ & FRIEDEL.
Ethylic dimethoxalate	$C_6 H_{12} O_3$	4·56	4·67	F. & D.
Ethylic ethyl-lactate	$C_7 H_{14} O_3$	5·03	5·052	WURTZ.
Ethylic ethomethoxalate	$C_7 H_{14} O_3$	5·03	4·98	F. & D.
Methylic diethoxalate	$C_7 H_{14} O_3$	5·03	4·84	„
Ethylic diethoxalate	$C_8 H_{16} O_3$	5·528	5·24	„
Ethylic amylhydroxalate	$C_9 H_{18} O_3$	6·01	5·47	„
Ethylic ethyl-amylhydroxalate	$C_{11} H_{22} O_3$	6·92	6·29	„
Amylic diethoxalate	$C_{11} H_{22} O_3$	6·92	6·74	„
Ethylic diamyloxalate	$C_{14} H_{28} O_3$	8·4	5·9	„

We have likewise prepared the acids corresponding to the three ethers above mentioned. The first is obtained by decomposing ethylic amylhydroxalate with baryta, treating the solution of the barium-salt thus obtained with excess of sulphuric acid, and then dissolving out the organic acid with ether. On evaporating the ethereal solution, the acid remains as a thick oil which does not crystallize after several days' exposure over sulphuric acid *in vacuo*. The calcium-salt forms a white crystalline mass soluble in water. Submitted to analysis, ·2102 grm. gave ·0877 grm. calcic sulphate, corresponding to 12·27 per cent. of calcium, the formula

$$C_{14}H_{26}Ca''O_6, \text{ or } \begin{array}{l}\left\{\begin{array}{l}C\,Ay\,H\,Ho\\ C\,O\,O\end{array}\right.\\ \left\{\begin{array}{l}C\,O\,O\\ C\,Ay\,H\,Ho\end{array}\right.\end{array} Ca''$$

requiring 12·12 per cent.

The barium-salt closely resembles that of calcium.

·2476 grm. gave on analysis ·1334 grm. baric sulphate, corresponding to 31·68 per cent. of barium. The formula

$$C_{14}H_{26}Ba''O_6, \text{ or } \begin{array}{l}\left\{\begin{array}{l}C\,Ay\,H\,Ho\\ C\,O\,O\end{array}\right.\\ \left\{\begin{array}{l}C\,O\,O\\ C\,Ay\,H\,Ho\end{array}\right.\end{array} Ba''$$

requires 32·08 per cent. of barium.

We have also obtained a beautifully crystalline acid of the same composition as the above, from its zinc-salt contained in the residue remaining after the distillation of the three ethers above described. *Amylhydroxalic acid* prepared from this zinc-salt is but sparingly soluble in water, from which, however, it crystallizes in magnificent nacreous scales that fuse at 60·5° C., but afterwards remain liquid for some time even at ordinary temperatures; they are very unctuous to the touch, and readily soluble in alcohol and ether. On analysis this acid gave the following results:—

I. ·1921 grm. gave ·4002 grm. carbonic anhydride and ·1702 grm. water.

II. ·1770 grm. gave ·3734 grm. carbonic anhydride and ·1556 grm. water.

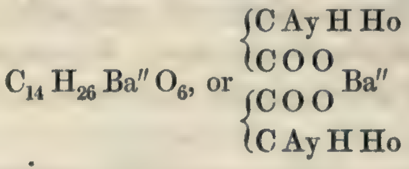
These numbers agree well with those calculated from the formula

$$C_7H_{14}O_3, \text{ or } \left\{\begin{array}{l}C\,Ay\,H\,Ho\\ C\,O\,Ho\end{array}\right.,$$

as the following comparison shows:—

	Calculated.		Found.		Mean.
			I.	II.	
C_7 . .	84	57·53	56·82	57·67	57·25
H_{14} . .	14	9·59	9·84	9·77	9·80
O_3 . .	48	32·88	——	——	——
	146	100·00			

The barium-salt of this acid crystallizes in large and beautiful nacreous scales like paraffin, tolerably soluble in water; ·3765 grm. gave on analysis ·2027 grm. baric sulphate, corresponding to 31·66 per cent. of barium. The formula



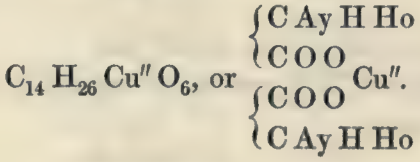
$$C_{14}H_{26}Ba''O_6,\ \text{or}\ \begin{array}{l}\left\{\begin{array}{l}C\,Ay\,H\,Ho\\ C\,O\,O\end{array}\right.\\ \left\{\begin{array}{l}C\,O\,O\\ C\,Ay\,H\,Ho\end{array}\right.\end{array} Ba''$$

requires 32·08 per cent. of barium.

A copper salt was also prepared. It is deposited from its aqueous solution in minute light-blue scales, very sparingly soluble in water.

Submitted to analysis, ·2341 grm. gave ·4045 grm. carbonic acid, ·1561 grm. water, and ·0528 grm. cupric oxide.

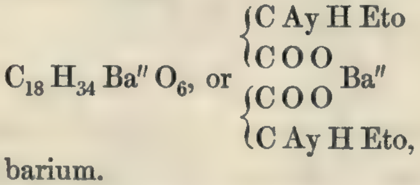
These numbers agree closely with the formula



$$C_{14}H_{26}Cu''O_6,\ \text{or}\ \begin{array}{l}\left\{\begin{array}{l}C\,Ay\,H\,Ho\\ C\,O\,O\end{array}\right.\\ \left\{\begin{array}{l}C\,O\,O\\ C\,Ay\,H\,Ho\end{array}\right.\end{array} Cu''.$$

	Calculated.		Found.
C_{14} . . .	168	47·52	47·13
H_{26} . . .	26	7·36	7·41
Cu . . .	63·5	17·95	18·01
O_6 . . .	96	27·17	27·45
	353·5	100·00	100·00

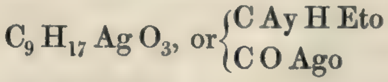
The acid of the second ether, *ethyl-amylhydroxalic acid*, is prepared by the decomposition of ethylic ethyl-amylhydroxalate with alcoholic potash. The acid is afterwards liberated by the addition of sulphuric acid in excess, and may then be dissolved out of the mixture by ether. On the evaporation of the latter, the acid remains as a thick oil gradually solidifying to a crystalline mass, which, however, did not appear to be in a fit state for the determination of its fusing-point. The barium- and silver-salts of this acid were prepared. They are both soluble in water; ·1331 grm. of baric ethyl-amylhydroxalate gave, on decomposition with sulphuric acid, ·0660 grm. baric sulphate, corresponding to 29·15 per cent. of barium, the formula



$$C_{18}H_{34}Ba''O_6,\ \text{or}\ \begin{array}{l}\left\{\begin{array}{l}C\,Ay\,H\,Eto\\ C\,O\,O\end{array}\right.\\ \left\{\begin{array}{l}C\,O\,O\\ C\,Ay\,H\,Eto,\end{array}\right.\end{array} Ba''$$

requiring 28·41 per cent. of barium.

·1891 grm. of argentic ethyl-amylhydroxalate gave on ignition ·0722 grm. metallic silver, representing 38·18 per cent. The formula



$$C_9H_{17}AgO_3,\ \text{or}\left\{\begin{array}{l}C\,Ay\,H\,Eto\\ C\,O\,Ago\end{array}\right.$$

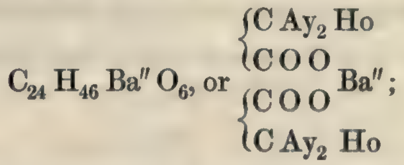
requires 38·43 per cent. of silver.

The acid of the third ether (*diamyloxalic acid*) is best prepared by decomposing the ether with boiling baryta-water. After removing the excess of baryta in the usual manner, baric diamyloxalate crystallizes on evaporation in minute elastic needles, which, when dry, have the appearance of wool. It is moderately soluble in hot water, but sparingly so in cold. Two determinations of barium in this salt gave the following results:—

I. ·2139 grm. of baric diamyloxalate gave ·0875 grm. baric sulphate.

II. ·2155 grm. gave ·0771 grm. baric carbonate.

These numbers agree with the formula



$$C_{24}H_{46}Ba''O_6, \text{ or } \begin{matrix}\left\{\begin{matrix}C\,Ay_2\,Ho\\ C\,O\,O\end{matrix}\right.\\ \left\{\begin{matrix}C\,O\,O\\ C\,Ay_2\,Ho\end{matrix}\right.\end{matrix} Ba'';$$

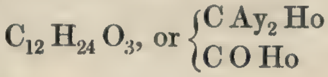
as shown by the following comparison of percentage numbers:—

	Experiment.			
	I.	II.	Mean.	Theory.
Percentage of barium . .	24·11	24·83	24·49	24·16.

If baric diamyloxalate be dissolved in hot dilute alcohol and excess of sulphuric acid be added, the liquid after filtration contains diamyloxalic acid in solution. On heating upon a water-bath, the alcohol gradually evaporates, and diamyloxalic acid crystallizes in the hot solution as a beautiful network of brilliant silky fibres, which after being well washed in cold water, and dried at 100°, yielded on analysis the following numbers:—

·1090 grm. gave ·2658 grm. carbonic anhydride and ·1103 grm. water.

This result agrees well with the formula



$$C_{12}H_{24}O_3, \text{ or } \left\{\begin{matrix}C\,Ay_2\,Ho\\ C\,O\,Ho\end{matrix}\right.$$

	Calculated.		Found.
C_{12} . .	144	66·66	66·51
H_{24} . .	24	11·11	11·24
O_3 . .	48	22·23	22·25
	216	100·00	100·00

Diamyloxalic acid presents the appearance of colourless satiny fibres, which are insoluble in water, but soluble in alcohol or ether. This acid is remarkable for its high melting-point, 122° C., in which respect it surpasses any of the acids of this series. Its melting-point is very sharply defined, and it solidifies immediately on a very slight reduction of temperature. Heated more strongly, it sublimes and condenses on a cold surface in white crystalline flakes like snow.

VI. *Action of Zinc upon a Mixture of Ethylic Iodide and Amylic Oxalate.*

Equivalent proportions of amylic oxalate and ethylic iodide were digested at 50° to 60° with excess of granulated zinc for several days. The reaction proceeded with extreme sluggishness, and was not completed before the expiration of a week. The mass being then mixed with water and submitted to distillation, an oily liquid passed over, which on rectification was ultimately resolved into amylic alcohol and an ethereal liquid. Submitted to analysis the latter yielded the following results:—

I. ·2508 grm. gave ·5999 grm. carbonic anhydride and ·2475 grm. water.

II. ·3299 grm. gave ·7850 grm. carbonic anhydride and ·3237 grm. water.

These numbers agree closely with those calculated from the formula of amylic diethoxalate,

$$C_{11}H_{22}O_3, \text{ or } \left\{\begin{matrix}\mathrm{C\,Et_2\,Ho} \\ \mathrm{C\,O\,Ayo}\end{matrix}\right. .$$

	Calculated.		Found. I.	Found. II.	Found. Mean.
C_{11}	132	65·34	65·23	64·90	65·07
H_{22}	22	10·89	10·96	10·90	10·93
O_3	48	23·77	——	——	24·00
	202	100·00			100·00

The two consecutive reactions by which amylic diethoxalate is produced are expressed in the following equations:—

$$\left\{\begin{matrix}\mathrm{C\,O\,Ayo} \\ \mathrm{C\,O\,Ayo}\end{matrix}\right. + Zn_4 + 4\,Et\,I = \left\{\begin{matrix}\mathrm{C\,Et_2(O\,Zn''Et)} \\ \mathrm{C\,O\,Ayo}\end{matrix}\right. + Zn''Et\,Ayo + 2\,Zn\,I_2;$$

Amylic oxalate. Amylic zincmonethyl-diethoxalate. Zincethylo-amylate.

$$\left\{\begin{matrix}\mathrm{C\,Et_2(O\,Zn''Et)} \\ \mathrm{C\,O\,Ayo}\end{matrix}\right. + 2H_2O = \left\{\begin{matrix}\mathrm{C\,Et_2\,Ho} \\ \mathrm{C\,O\,Ayo}\end{matrix}\right. + Et\,H + Zn''Ho_2.$$

Amylic zincmonethyl-diethoxalate. Amylic diethoxalate. Zincic hydrate.

Amylic diethoxalate is a colourless, transparent, and slightly oily liquid, possessing a fragrant odour of a somewhat amylic character. It is insoluble in water, but miscible in all proportions with alcohol and ether. Its specific gravity is ·93227 at 13° C. It boils constantly at 225° C. A determination of its vapour-density gave the following data:—

Weight of amylic diethoxalate	·1999 grm.
Observed volume of vapour	49·8 cub. centims.
Temperature of bath	246° C.
Height of barometer	752 millims.
Difference of height of mercury inside and outside tube . . .	104 millims.
Height of spermaceti column reduced to millimetres of mercury	14·24 millims.

These numbers indicate a density of 6·74, the above formula requiring 6·97.

Amylic diethoxalate is isomeric with ethylic ethyl-amylhydroxalate described above. The nature of this isomerism is seen at a glance from the following rational formulæ of the two bodies:—

Ethylic ethyl-amylhydroxalate . . . . . $\left\{\begin{matrix}\mathrm{C\,Ay\,H\,Eto}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.$

Amylic diethoxalate . . . . $\left\{\begin{matrix}\mathrm{C\,Et_2\,Ho}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.$

The specific gravities, in the liquid form, and the boiling-points of amylic diethoxalate and its isomer ethylic ethyl-amylhydroxalate, are almost absolutely identical, viz.

	Boiling-point.	Specific gravity.
Ethylic ethyl-amylhydroxalate .	224°–225° C.	·9399 at 13° C.
Amylic diethoxalate	225° C.	·9322 at 13° C.

They are, however, at once distinguished by the products of their decomposition with alkalies, ethylic ethyl-amylhydroxalate giving ethylic alcohol and a salt of ethyl-amylhydroxalic acid, whilst amylic diethoxalate yields amylic alcohol and a salt of diethoxalic acid.

VII. *Action of Zinc upon a Mixture of Amylic Iodide and Amylic Oxalate.*

When equivalent proportions of amylic iodide and amylic oxalate are gently heated in contact with zinc, a brisk reaction soon sets in. After evolving much amylic hydride and amylene, the whole solidifies to a gum-like mass, which, on distillation with water, yields an oily liquid resembling that obtained when ethylic oxalate is employed. We have every reason to believe that the same series of ethers as those described under No. V. are here produced, with the difference that they are amylic instead of ethylic ethers. This difference of base, however, renders the separation of these ethers from each other a very difficult operation, and we have therefore left this reaction comparatively unexplored. Two of these ethers were, however, collected; the one boiling at about 280°–290° C. exhibited a composition approaching that of *amylic diamyloxalate*,

$$\mathrm{C_{17}\,H_{34}\,O_3},\ \text{or}\ \left\{\begin{matrix}\mathrm{C\,Ay_2\,Ho}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.;$$

as the following analytical results show:—

I. ·1734 grm. gave ·4495 grm. carbonic anhydride and ·1781 grm. water.

II. ·1990 grm. gave ·5187 grm. carbonic anhydride and ·2068 grm. water.

	Calculated.		Found.		
			I.	II.	Mean.
C_{17} . .	204	71·33	71·00	71·08	71·04
H_{34} . .	34	11·88	11·41	11·54	11·47
O_3 . .	48	16·79	——	——	17·49
	286	100·00			100·00

Amylic diamyloxalate is doubtless produced by the following consecutive reactions:—

$$\underset{\text{Amylic oxalate.}}{\left\{\begin{matrix}\mathrm{C\,O\,Ayo}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.} + \mathrm{Zn_4} + 4\,\mathrm{Ay\,I} = \underset{\text{Amylic zincmonamyl-diamyloxalate.}}{\left\{\begin{matrix}\mathrm{C\,Ay_2(O\,Zn''\,Ay)}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.} + \underset{\text{Zincic amylo-amylate.}}{\mathrm{Zn''\,Ay\,Ayo}} + 2\,\mathrm{Zn''\,I_2}$$

$$\underset{\text{Amylic zincmonamyl-diamyloxalate.}}{\left\{\begin{matrix}\mathrm{C\,Ay_2(O\,Zn''\,Ay)}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.} + 2\,\mathrm{H_2\,O} = \underset{\text{Amylic di-amyloxalate.}}{\left\{\begin{matrix}\mathrm{C\,Ay_2\,Ho}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right.} + \underset{\text{Amylic hydride.}}{\mathrm{Ay\,H}} + \mathrm{Zn''\,Ho_2}.$$

The second ether mentioned above boiled between 215° and 220° C.; it was decomposed by alcoholic potash; the potash-salt so obtained, heated with dilute sulphuric acid, yielded to ether an oily acid possessing the characteristic odour of caproic acid. This acid, boiled with argentic carbonate suspended in water, gave on filtration magnificent nacreous plates of a silver-salt which were very sparingly soluble in water, only slightly acted upon by light, in fact possessing all the properties of normal silver caproate, and differing markedly from the isomeric silver diethacetate recently described by us*. Submitted to analysis this salt yielded the following results:—

·1517 grm. gave ·1776 grm. carbonic anhydride, ·0685 grm. water, and ·0729 grm. metallic silver.

These numbers agree closely with those calculated from the formula of silver caproate, as seen from the following comparison:—

$$\mathrm{C_6\,H_{11}\,Ag\,O_2}, \text{ or } \left\{\begin{matrix}\mathrm{C\,Bu\,H_2}\\ \mathrm{C\,O\,Ago,}\end{matrix}\right. \text{ or } \mathrm{C\,Ay\,O\,Ago}.$$

	Calculated.		Found.
C_6 . . .	72	32·29	32·02
H_{11} . . .	11	4·93	5·02
Ag . . .	108	48·43	48·06
O_2 . . .	32	14·35	14·90
	223	100·00	100·00

Unfortunately we did not submit to analysis the ether from which this caproic acid was obtained; but there can scarcely be a doubt that it was amylic caproate. We have stated that it boiled between 215° and 220°. The boiling-point of amylic caproate is not known; but ethylic caproate boils, according to FEHLING, at 162° C.; consequently the boiling-point of amylic caproate ought to be, according to KOPP'S law, 216° C., a number which lies between the points observed in the ether under consideration.

It is thus evident that the three variations in the action of zincamylide upon an oxalic ether, described above as giving rise to amylhydroxalic acid, ethyl-amylhydroxalic acid, and diamyloxalic acid, do not exhaust the fertility of this reaction; and the production of caproic acid, as above described, shows that the action of these substances upon each other is susceptible of yet a fourth modification, in which the molecule of amylic oxalate appears to divide into its two constituent atoms of amyloxatyl ($\mathrm{C\,O\,Ayo}$), which then unite with amyl to form amylic caproate.

---

* Philosophical Transactions, vol. clvi. p. 37.

$$\left\{\begin{matrix}\mathrm{C\,O\,Ayo}\\ \mathrm{C\,O\,Ayo}\end{matrix}\right. + \mathrm{Ay}_2 = 2\,\mathrm{C\,Ay\,O\,Ayo}, \text{ or } 2\left\{\begin{matrix}\mathrm{C\,Bu\,H}_2\\ \mathrm{C\,O\,Ayo}\end{matrix}\right..$$

Amylic oxalate. Amyl. Amylic caproate.

The source of the amyl in this reaction is not difficult to discover; for, as above stated, torrents of the usual products of its transformation (amylic hydride and amylene) were evolved during the operation; in fact it was obvious that no inconsiderable portions of the zinc and amylic iodide were occupied in the formation of zincic iodide and amyl, a considerable proportion of the latter being as usual transformed at the moment of separation into amylic hydride and amylene.

$$2\,\mathrm{Ay\,I} + \mathrm{Zn}'' = \mathrm{Zn}''\,\mathrm{I}_2 + \mathrm{Ay}_2.$$

Meeting with this reaction, as we have done, only at the close of the above investigation, we have not been able to ascertain whether or not it is one of general occurrence. It is true that we have not observed the formation of the fatty ethers in any of the foregoing reactions in which zinc and the iodides of the radicals were employed; but the comparatively low boiling-points of these ethers might easily have led to their having been overlooked. We consider, however, this reaction of so much importance, that we shall at once endeavour to ascertain whether or not it occurs in the other homologous cases, giving rise to acetic ether in the case of methylic iodide, and to propionic ether where ethylic iodide is employed.

We have already stated that the constitution of the acids of the lactic series has been the subject of fruitful controversy amongst chemists. In this discussion widely different opinions have been advanced: some have assigned to lactic acid the formula ($\mathrm{C_6\,H_{12}\,O_6}$), and attributed to it a dibasic character; some have reduced this formula to $\mathrm{C_3\,H_6\,O_3}$, still retaining for the acid the same degree of basicity; whilst others, again, have regarded it as monobasic, and assigned to it the lower formula. This controversy respecting the constitution of an acid so intimately related to several of the most important families of organic compounds, has been the incentive to numerous and highly important researches, which have thrown valuable light not merely upon the structure of the lactic series itself, but also upon that of organic families allied with this series.

Amongst the experimental investigations which have contributed to the elucidation of this subject, we beg leave to refer to those of WURTZ[*], ULRICH[†], STRECKER[‡], BRÜNING[§], PERKIN, and DUPPA[||]. Again, WURTZ, PERKIN, KEKULÉ, and especially KOLBE, have, by their acute theoretical speculations, most ably supplemented direct investigation.

---

[*] Comptes Rendus, vol. lii. p. 1067.

[†] Ann. der Chem. und Pharm. vol. cix. p. 271.

[‡] Ann. der Chem. und Pharm. vol. xci. p. 352.

[§] Ibid. vol. civ. p. 191.

[||] Ibid. vol. cviii. p. 113.

Unfortunately these researches and discussions were, to a great extent, limited to two members of this series, viz. lactic and glycolic acids, and this circumstance necessarily furnished a comparatively small basis upon which to build purely theoretical speculations. We are therefore not without hope that, with the addition of the numerous members of this series described in the foregoing pages, and with the light thrown upon them by their synthetical production, we have reached a new stage in the inquiry, whence a more extensive prospect may be obtained.

Before proceeding to take a survey of the new field thus opened up, it is necessary first to call special attention to a negative or chlorous organic radical intimately connected with the compounds above described.

The Radical Oxatyl.

An inspection of the above and following formulæ for acids of the lactic series shows that, through all the changes of the lactic acid type giving rise to the various species of acids mentioned below, the group $\mathrm{C\,O\,Ho}$ remains unaltered. We have also shown that the same group maintains its individuality unimpaired throughout the acetic and acrylic series of acids; in fact it is the presence of this group which impresses upon an organic compound the acid character. We believe, therefore, that its claims to be considered a compound radical are at least equal to those of any other group of elements to which that term has been applied.

We propose for this radical the name *oxatyl*[*]—a word recalling at the same time its acidifying power, and its connexion with oxalic acid, which is the isolated molecule of this radical,

$$\left\{\begin{matrix}\mathrm{C\,O\,Ho}\\ \mathrm{C\,O\,Ho}\end{matrix}\right..$$

Oxalic acid.

We have, in fact, experimentally proved above, that when ethylic oxalate is acted upon by nascent amyl, it is converted into ethylic caproate,

$$\underset{\text{Ethylic oxalate.}}{\left\{\begin{matrix}\mathrm{C\,O\,Eto}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.} + \underset{\text{Amyl.}}{\left\{\begin{matrix}\mathrm{C\,Bu\,H_2}\\ \mathrm{C\,Bu\,H_2}\end{matrix}\right.} = \underset{\text{Ethylic caproate.}}{2\left\{\begin{matrix}\mathrm{C\,Bu\,H_2}\\ \mathrm{C\,O\,Eto}\end{matrix}\right.}.$$

Oxatyl is closely related to cyanogen, the two radicals passing into each other in a host of reactions; hence the production of cyanides from the ammonium salts of the fatty acids on the one hand, and the synthesis of acids from certain cyanogen compounds on the other—a reaction first pointed out by KOLBE and FRANKLAND[†], and which has of late yielded such magnificent results in the hands of MAXWELL SIMPSON[‡] and of KOLBE and HUGO MÜLLER[§].

---

[*] *Oxalyl* would obviously be the most appropriate name for this radical, had it not already been applied to the two compounds $\mathrm{C\,O}$ and $\mathrm{C_2\,O_2}$. Whilst this paper is passing through the press we find that the radical oxatyl has already been fully recognized by BUTLEROW.

[†] Memoirs of Chem. Soc. vol. iii. (1847) p. 386.

[‡] Philosophical Transactions, 1861, p. 61; and Journ. Chem. Soc. vol. xviii. p. 331.

[§] Journ. Chem. Soc. vol. xvii. p. 109.

$$\underset{\text{Cyanogen.}}{\left\{\begin{matrix}C\,N'''\\C\,N'''\end{matrix}\right.}. \qquad \underset{\text{Oxatyl.}}{\left\{\begin{matrix}C\,O\,Ho\\C\,O\,Ho\end{matrix}\right.}.$$

The researches of these chemists prove that the introduction of cyanogen into an organic compound, and its subsequent transformation into oxatyl, converts that compound into an acid, or, if already an acid, increases its basicity by unity for each atom of oxatyl so developed, this result being apparently quite independent of the position of the oxatyl in the molecule.

The atom of oxatyl, as the above molecular formula shows, may be regarded as methyl ($C\,H_3$) in which two atoms of hydrogen have been replaced by one of oxygen, and the third by hydroxyl (Ho). The individualizing of this group confers upon the formulæ of most of the great families of organic compounds a simplicity hitherto unattainable without ignoring their atomic constitution. The passage from one organic family to another thus becomes a mere substitution of the hydroxyl contained in oxatyl by other radicals, either simple or compound. When, for instance, it is replaced by the peroxide of a metal, the acid of which the oxatyl is a constituent becomes converted into a salt; thus

Sodic acetate . . . . . . $\left\{\begin{matrix}C\,H_3\\C\,O\,Nao\end{matrix}\right.$.

Baric acetate . . . . . $\begin{matrix}\left\{\begin{matrix}C\,H_3\\C\,O\end{matrix}\right. & \\ & Bao''. \\ \left\{\begin{matrix}C\,O\\C\,H_3\end{matrix}\right. & \end{matrix}$

Sodic succinate . . . $C_2\,H_4\begin{matrix}C\,O\,Nao\\C\,O\,Nao\end{matrix}$.

Baric succinate . . . $C_2\,H_4\begin{matrix}C\,O\\C\,O\end{matrix}Bao''$.

With the hydroxyl replaced by methoxyl, ethoxyl, &c., an ethereal salt is produced, as

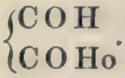
Ethylic acetate . . . . $\left\{\begin{matrix}C\,H_3\\C\,O\,Eto\end{matrix}\right.$.

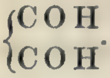
Ethylic succinate . . . . . . $C_2\,H_4\begin{matrix}C\,O\,Eto\\C\,O\,Eto\end{matrix}$.

Ethylic citrate . . . . $\left\{\begin{matrix}C\,H\,Ho(C\,O\,Eto)\\C\,H(C\,O\,Eto)\\C\,H_2(C\,O\,Eto)\end{matrix}\right.$.

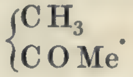
When the hydroxyl is replaced by hydrogen, an aldehyde or an aldehydoid acid is the result. Thus,

Aldehyde . . . . $\left\{\begin{matrix}C\,H_3\\C\,O\,H\end{matrix}\right.$.

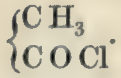
Glyoxylic acid . . .

$\left\{\begin{matrix}C\,O\,H\\C\,O\,Ho\end{matrix}\right.$.

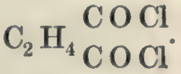
Glyoxal . . . . .

$\left\{\begin{matrix}C\,O\,H\\C\,O\,H\end{matrix}\right.$.

Again, if a basylous monad radical take the place of the hydroxyl, a ketone is formed,

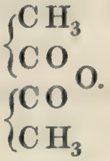
Acetone . . . . .

$\left\{\begin{matrix}C\,H_3\\C\,O\,Me\end{matrix}\right.$.

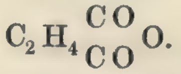
Further, if chlorine, bromine, &c. replace the hydroxyl, a haloid compound of the so-called "acid radical" is the result:

Acetylic chloride . . . . .

$\left\{\begin{matrix}C\,H_3\\C\,O\,Cl\end{matrix}\right.$.

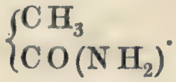
Succinylic chloride . . .

$C_2\,H_4\begin{matrix}C\,O\,Cl\\C\,O\,Cl\end{matrix}$.

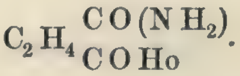
Again, if the hydroxyl be replaced by oxygen, an anhydride is formed:

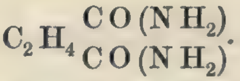
Acetic anhydride . . . . .

$\begin{matrix}\left\{\begin{matrix}C\,H_3\\C\,O\end{matrix}\right.\\\left\{\begin{matrix}C\,O\\C\,H_3\end{matrix}\right.\end{matrix}O.$

Succinic anhydride . . .

$C_2\,H_4\begin{matrix}C\,O\\C\,O\end{matrix}O.$

And, finally, if replaced by amidogen, an amide or amido-acid results:

Acetamide . . . .

$\left\{\begin{matrix}C\,H_3\\C\,O\,(N\,H_2)\end{matrix}\right.$.

Succinamic acid . . . .

$C_2\,H_4\begin{matrix}C\,O\,(N\,H_2)\\C\,O\,Ho\end{matrix}$.

Succinamide . . . . .

$C_2\,H_4\begin{matrix}C\,O\,(N\,H_2)\\C\,O\,(N\,H_2)\end{matrix}$.

It may be objected that the group of elements which is thus invested with radical functions, lacks one of the fundamental characteristics of a radical by its proneness to change; but this characteristic is exhibited by the commonly received radicals in a very varied degree; and even methyl itself, which certainly possesses it in the most marked manner, readily permits of its hydrogen being replaced by chlorine or bromine on the one hand, and by sodium on the other.

All compound radicals are purely conventional groupings of elements, intended to simplify the expression of chemical change; and in this respect we believe the group oxatyl, entering as it does into the constitution of nearly every organic acid, has as valid a claim to a distinct name as the most universally recognized radicals. Its admission renders possible the following very simple expression of the law governing the basicity of nearly all organic acids:—

An organic acid containing n *atoms of oxatyl is* n*-basic.*

Classification of the Acids of the Lactic Series.

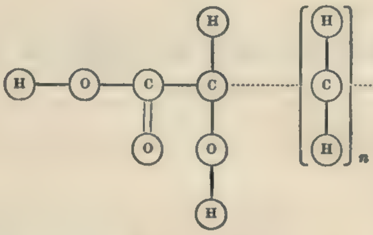
We propose classifying all acids of the lactic series at present known, or which could be obtained by obvious processes, into the following eight divisions:—

1. Normal Acids.
2. Etheric Normal Acids.
3. Secondary Acids.
4. Etheric Secondary Acids.
5. Normal Olefine Acids.
6. Etheric Normal Olefine Acids.
7. Secondary Olefine Acids.
8. Etheric Secondary Olefine Acids.

1st. *Normal Acids.*—A normal acid of the lactic series may be defined as one in which an atom of carbon is united with oxatyl, hydroxyl, and at least one atom of hydrogen. The general formula of these acids is therefore

$$\left\{\begin{array}{l}\mathrm{C}\,\overset{+}{\mathrm{R}}\,\mathrm{H}\,\mathrm{Ho}\\ \mathrm{C}\,\mathrm{O}\,\mathrm{Ho}\end{array}\right. .$$

In this formula $\overset{+}{\mathrm{R}}$ may be either hydrogen or any monad alcohol radical; and the number of acids possessing the same atomic weight, and belonging to this division, is determined by the number of isomeric modifications of which the alcohol radical is susceptible. Thus, of the acids containing two, three, or four atoms of carbon, there can be only one of each belonging to this division, because these acids cannot contain an alcohol radical higher in the series than ethyl, which is not susceptible of isomeric modification; but a normal acid containing propyl can have one isomer in this division, the two acids containing respectively propyl ($\mathrm{C\,Et\,H_2}$) and isopropyl ($\mathrm{C\,Me_2\,H}$). For acids of this division containing normal alcohol radicals only, the following general graphic formula may be given:—



In the case of glycollic acid $n=0$.

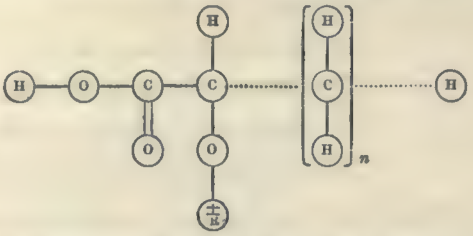
The following are the acids at present known belonging to this division*:—

Glycollic acid	$\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.
Lactic acid	$\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.
Oxybutyric acid	$\left\{\begin{array}{l}\mathrm{C\,Et\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.
Leucic acid	$\left\{\begin{array}{l}\mathrm{C\,Bu\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.

---

* Since the above was written Fittig has produced valerolactic acid, the rational formula of which is doubtless $\left\{\begin{array}{l}\mathrm{C\,Pr\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.—April 29th, 1866.

2nd. *Etheric Normal Acids.*—An etheric normal acid of the lactic series is constituted like a normal acid, but contains a monad organic radical, chlorous or basylous, in the place of the hydrogen of the *non-oxatylic* hydroxyl. The following is therefore the general formula of these acids: in the graphic formula n, as before, may $=0$.



or $\left\{\begin{matrix} \mathrm{C\,\overset{+}{R}\,H\,\overset{\pm}{R}o} \\ \mathrm{C\,O\,Ho} \end{matrix}\right.$.

The number of possible isomers belonging to this division is very great; for, in addition to those of which the normal acids containing $\overset{+}{R}$ of the same value are susceptible, a host of others must result from the complementary variation of $\overset{+}{R}$ and $\overset{\pm}{R}$. The lowest member of the division, methylglycollic acid (isomeric with lactic acid), is the only one incapable of isomeric modification.

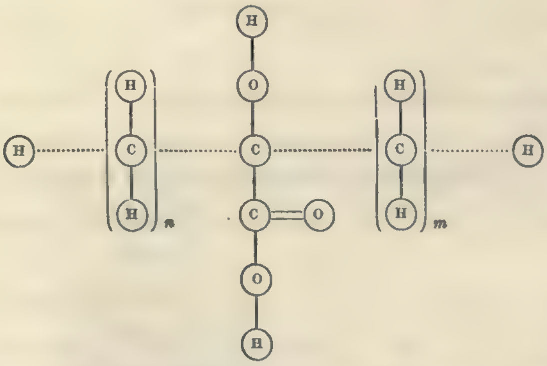
The following examples will serve to illustrate the constitution of the acids belonging to this division:—

Methylglycollic acid . . . . $\left\{\begin{matrix} \mathrm{C\,H_2\,Meo} \\ \mathrm{C\,O\,Ho} \end{matrix}\right.$.

Ethyl-lactic acid . . . . $\left\{\begin{matrix} \mathrm{C\,Me\,H\,Eto} \\ \mathrm{C\,O\,Ho} \end{matrix}\right.$.

Aceto-lactic acid . . . . $\left\{\begin{matrix} \mathrm{C\,Me\,H\,Aco}* \\ \mathrm{C\,O\,Ho} \end{matrix}\right.$.

3rd. *Secondary Acids.*—A secondary acid of the lactic series is one in which an atom of carbon is united with oxatyl, hydroxyl, and *two atoms* of an alcohol radical. The general formula of these acids is



or $\left\{\begin{matrix} \mathrm{C\,\overset{+}{R}_2\,Ho} \\ \mathrm{C\,O\,Ho} \end{matrix}\right.$

In the graphic expression the values of n and m may differ; but both are positive integers, and neither may $=0$. In the symbolic formula $\overset{+}{R}$ must be a monad alcohol radical. All the known members of this division are described in the foregoing pages. The following examples will serve to illustrate their constitution:—

---

* Aco=peroxide of acetyl, $C_2H_3O_2$.

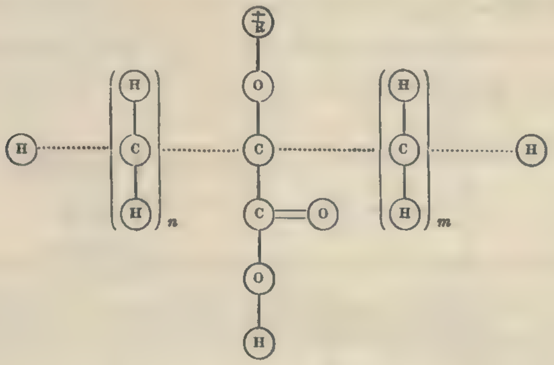
Dimethoxalic acid . . . . $\left\{\begin{array}{l} C\,Me_2\,Ho \\ C\,O\,Ho \end{array}\right.$.

Ethomethoxalic acid . . . . $\left\{\begin{array}{l} C\,Et\,Me\,Ho \\ C\,O\,Ho \end{array}\right.$.

Diethoxalic acid . . . . $\left\{\begin{array}{l} C\,Et_2\,Ho \\ C\,O\,Ho \end{array}\right.$.

The number of acids possessing the same atomic weight, and belonging to this division, is determined, first, by the complementary variation of the two alcohol radicals, and, secondly, by the number of possible isomers of these radicals. The two lowest terms of the series are alone incapable of isomeric modification by either of the causes mentioned.

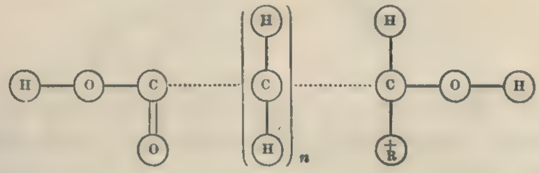
4th. *Etheric Secondary Acids.*—These acids stand in the same relation to the secondary as the etheric normal to the normal acids; they consequently contain a monad organic radical in the place of the hydrogen of the non-oxatylic hydroxyl. The following is therefore the general formula of these acids:—



or $\left\{\begin{array}{l} C\,\overset{+}{R}_2\,\overset{\pm}{R}o \\ C\,O\,Ho \end{array}\right.$.

We have obtained acids belonging to this division which we hope to describe in an early communication.

5th. *Normal Olefine Acids.*—A normal olefine acid belonging to the lactic series is one in which the atom of carbon united with oxatyl is *not* combined with hydroxyl, and in which the atom of carbon united with hydroxyl is combined with not less than one atom of hydrogen. The following are the general graphic and symbolic formulæ of the acids belonging to this division:—



or $\left\{\begin{array}{l} C\,\overset{+}{R}\,H\,Ho \\ (C\,H_2)_n \\ C\,O\,Ho \end{array}\right.$

In both these formulæ n must be a positive integer and cannot $=0$, but $\overset{+}{R}$ may be either hydrogen or a monad alcohol radical. The olefines of these acids may belong to either the ethylene or ethylidene series.

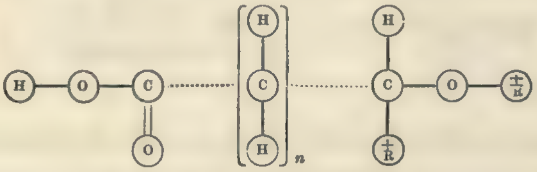
The following are the only acids at present known belonging to this division:—

Paralactic acid . . . . . $\left\{\begin{array}{l} C\,H_2\,Ho \\ C\,H_2 \\ C\,O\,Ho \end{array}\right.$.

Paraleucic acid . . . . . $\left\{\begin{array}{l} C\,H_2\,Ho \\ C_4\,H_8 \\ C\,O\,Ho \end{array}\right.$.

We give the name paraleucic acid to the acid obtained by LIPPMANN* in acting with phosgene gas upon amylene. This body has not yet been completely investigated; LIPPMANN regards it as identical with leucic acid; but as it is produced by a reaction exactly homologous with that by which paralactic acid is formed, we believe it will be found to differ slightly from leucic acid, as paralactic does from lactic acid. The number of isomers in this division will obviously depend, first, upon the complementary variations of $\overset{+}{R}$ and $(C\,H_2)_n$; secondly, upon the isomeric modifications of which $\overset{+}{R}$ is susceptible; and thirdly, upon the isomeric modifications of $(C\,H_2)_n$.

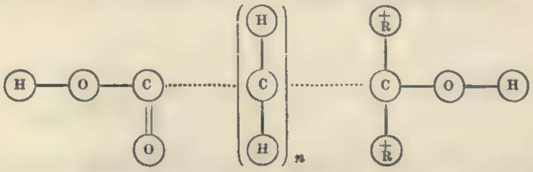
6th. *Etheric Normal Olefine Acids.*—These acids only differ from the normal olefine acids in having the hydrogen of the non-oxatylic hydroxyl replaced by an organic radical positive or negative; therefore their general formula is



or $\left\{\begin{array}{l} C\,\overset{+}{R}\,H\,\overset{\pm}{R}o \\ (C\,H_2)_n \\ C\,O\,Ho \end{array}\right.$

As in the fifth division, n must be a positive integer and cannot $=0$, whilst $\overset{+}{R}$ may be either hydrogen or a monad alcohol radical; but $\overset{\pm}{R}$ must be a monad compound radical, either acid or alcoholic.

7th. *Secondary Olefine Acids.*—A secondary olefine acid of this series is one in which the atom of carbon united with oxatyl is *not* combined with hydroxyl, and in which the atom of carbon united with hydroxyl is also combined with two monad alcohol radicals, as shown in the following formulæ:—



or $\left\{\begin{array}{l} C\,\overset{+}{R}_2\,Ho \\ (C\,H_2)_n \\ C\,O\,Ho \end{array}\right.$

In both of these formulæ n must be a positive integer and cannot $=0$, and $\overset{+}{R}$ must be a monad alcohol radical.

---

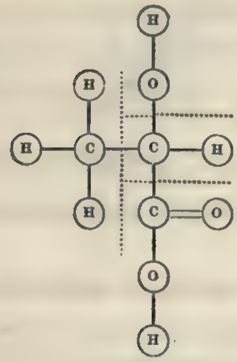
* Ann. der Ch. und Pharm. Bd. cxxix. s. 81.

8th. *Etheric Secondary Olefine Acids.*—These acids are related to the secondary olefine acids in the same way as the sixth division to the fifth. No member of the seventh or eighth division has yet been formed.

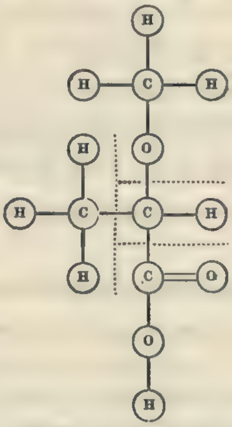
Isomerism in the Lactic Series.

The members of the lactic series may be defined as acids containing one atom of oxatyl, the fourth bond of the carbon of which is united with the carbon of a basylous group containing one atom, and one only, of hydroxyl, or of the peroxide of a radical, either alcoholic or acid. The following examples, expressed in the graphic notation of Crum Brown*, will serve to illustrate this definition.

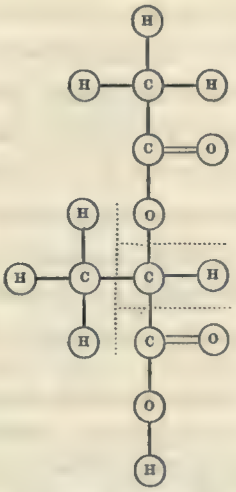
Acids of the Lactic Series.



Lactic acid.

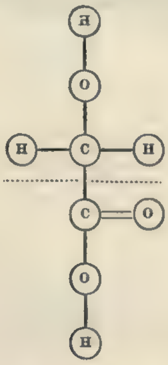


Methyl-lactic acid.



Aceto-lactic acid.

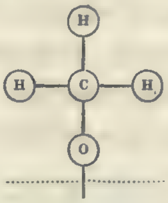
The synthetical study of the acids of this series affords an insight into numerous and interesting cases of isomerism, which have hitherto received, at best, but a very imperfect explanation. Commencing with the lowest member of the series, we have for glycollic acid



---

* Edinburgh Phil. Trans. for 1864, p. 707. It is much to be desired that chemists should employ these graphic formulæ in all cases where they wish to express the mode in which they suppose the elements of a chemical compound to be combined. It is often extremely difficult to trace in symbolic formulæ, the exact meaning which the author attaches to the grouping of letters; in graphic formulæ no such difficulty can arise;

An inspection of this formula shows that glycollic acid admits of no isomeric modification, except with a total change of type, *unless a different value be assigned to the individual bonds of an atom of carbon.* The part of the formula below the dotted line represents oxatyl, which, as we have already shown, cannot be altered without sacrificing the acid character of the compound; there remains therefore only the part of the formula above the dotted line, which admits of the following modification:—



The acid represented by the formula so modified no longer comes within our definition of the lactic series. It is carbomethylic acid, and differs essentially from glycollic acid and the lactic series in general, inasmuch as the carbon of its chlorous radical, oxatyl, is linked to the carbon of the basylous radical by oxygen*.

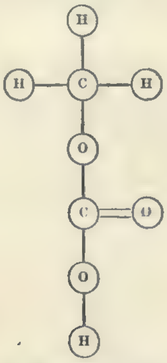
There being no decisive evidence that homolactic acid differs from glycollic acid, experiment and theory both agree in asserting that the formula $C_2 H_4 O_3$ represents only one acid in the lactic series.

Proceeding now one step higher in this series, we have in the formula of lactic acid an expression capable of the following three variations without quitting the lactic type:—

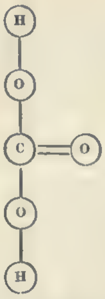
---

and we therefore think that the use of these formulæ, where constitutional expressions are intended, will greatly tend to clearness and precision. It is scarcely necessary to repeat CRUM BROWN'S remark, that such formulæ are not meant to indicate the physical, but merely the chemical position of the atoms. For the purpose of rendering the graphic more easy of comparison with symbolic formulæ, we have sometimes dissected the former into their constituent radicals by dotted lines, as above. This dissection, whilst assisting the eye in reading the formulæ, cannot fail to suggest the, for the most part, purely conventional character of such radicals.

* Bearing this constitution of carbomethylic acid in mind, we have only to go one step further in order to perceive the constitution of carbonic acid itself, and the anomalous basicity of that acid; for if, in the above graphic formula, for carbomethylic acid we replace the methyl by hydrogen, we have



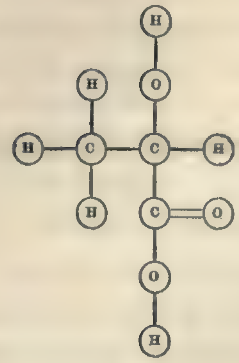
Carbomethylic acid.



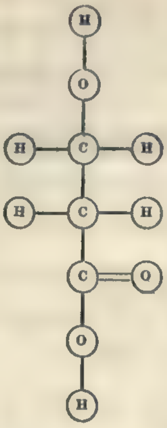
Carbonic acid.

It is thus evident that our radical oxatyl, when united with hydroxyl, has sufficient chlorous power to produce a feebly dibasic acid, but inasmuch as carbonic acid is not included in the category of organic acids, it forms no exception to the law above enunciated.

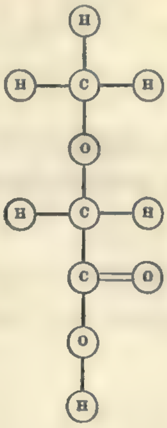
No. 1.



No. 2.



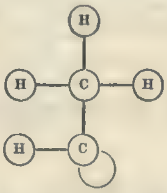
No. 3.



Or, expressed symbolically,

No. 1. $\left\{\begin{matrix} C\,Me\,H\,Ho \\ C\,O\,Ho \end{matrix}\right.$. No. 2. $\left\{\begin{matrix} C\,H_2\,Ho \\ C\,H_2(C\,O\,Ho) \end{matrix}\right.$, or $\left\{\begin{matrix} C\,H_2\,Ho \\ C\,H_2 \\ C\,O\,Ho \end{matrix}\right.$. No. 3. $\left\{\begin{matrix} C\,H_2\,Meo \\ C\,O\,Ho \end{matrix}\right.$.

All the acids represented by the above formulæ are known. The first expresses the constitution of lactic acid, which belongs to the normal division $\left(\left\{\begin{matrix} C\,\overset{+}{R}\,H\,Ho \\ C\,O\,Ho \end{matrix}\right.\right)$ of the series described at page 345, the second shows the atomic arrangement of paralactic acid, whilst the third represents methyl-glycollic acid. The proof that the first two of these acids are so constituted, is afforded by the beautiful synthetic processes for their production devised by WISLICENUS[*] and LIPPMANN[†]. The first of these chemists has shown, namely, that ethylidene cyanhydrate is converted by ebullition with potash into a salt of lactic acid, whilst ethylene cyanhydrate is transformed under similar circumstances into paralactic acid. LIPPMANN has also shown that by the action of phosgene gas upon ethylene, paralactic acid is produced. Now the formation of ethylidene, or rather of its compounds, scarcely leaves a doubt that this body, if isolated, would have the following atomic constitution:—



or $\left\{\begin{matrix} C\,H_3 \\ C\,H \end{matrix}\right.$:

it would consist of an atom of methyl united with an atom of carbon, two of whose bonds satisfy each other. Thus the formation of ethylidene dichloride from aldehyde and phosphoric chloride takes place as follows:—

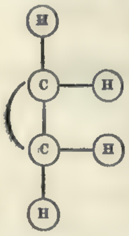
---

[*] Ann. der Ch. und Pharm. Bd. cxxviii. S. 1.

[†] *Ibid.* Bd. cxxix. S. 81. CRUM BROWN has already pointed out this relation between lactic and paralactic acids, as well as the formula of ethylene given below.—Edinburgh Phil. Trans. for 1864, p. 712.

$$\underset{\text{Aldehyde.}}{\left\{\begin{matrix}C\,H_3\\ C\,H\,O\end{matrix}\right.}+P\,Cl_5=\underset{\text{Ethylidene dichloride.}}{\left\{\begin{matrix}C\,H_3\\ C\,H\,Cl_2\end{matrix}\right.}+P\,O\,Cl_3,$$

the oxygen in the aldehyde being simply replaced by chlorine. There now only remains one possible formula for ethylene, viz.



or $\left\{\begin{matrix}C\,H_2\\ C\,H_2\end{matrix}\right..$

Such, then, being the constitution of ethylidene and ethylene, it follows that the former ought to give rise to an acid of the constitution shown in formula No. 1, whilst ethylene should produce an acid agreeing with formula No. 2. The acids actually produced from these sources are lactic and paralactic acids; hence we believe No. 1 to be the constitutional formula of lactic acid, and No. 2 that of paralactic acid, a conclusion which harmonizes perfectly with all the reactions in which the production of these acids can be traced. Thus in the formation of lactic acid by the oxidation of propylic glycol *, we have

$$\underset{\text{Propylic glycol.}}{\left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,H_2\,Ho\end{matrix}\right.}+O_2=\underset{\text{Lactic acid.}}{\left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Ho\end{matrix}\right.}+H_2\,O.$$

Again, the production of this acid from ethylidene cyanhydrate,

$$\underset{\text{Ethylidene cyanhydrate.}}{\left\{\begin{matrix}C\,H_3\\ C\,H\,Ho\,Cy\end{matrix}\right.}+K\,H\,O+H_2\,O=\underset{\text{Potassic lactate.}}{\left\{\begin{matrix}C\,H_3\\ C\,H\,Ho(C\,O\,Ko)\end{matrix}\right.}+N\,H_3.$$

The formula given for potassic lactate in this equation is only apparently different in type from that previously used for lactic acid, since

$$\left\{\begin{matrix}C\,H_3\\ C\,H\,Ho(C\,O\,Ko)\end{matrix}\right.=C\,Me\,H\,Ho(C\,O\,Ko)=\left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Ko\end{matrix}\right..$$

In ULRICH'S † interesting reaction, by which chloropropionic acid is transformed into lactic acid, we have the following change:

$$\underset{\text{Chloropropionic acid.}}{\left\{\begin{matrix}C\,Me\,H\,Cl\\ C\,O\,Ho\end{matrix}\right.}+2K\,Ho=\underset{\text{Potassic lactate.}}{\left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Ko\end{matrix}\right.}+K\,Cl+H_2\,O.$$

The production of lactamic acid (alanin), and that of lactic acid from the latter by the action of nitrous acid, are also clearly confirmatory of the above view.

---

* WURTZ, Ann. der Chem. und Pharm. Bd. cv. S. 205.

† Ann. der Chem. und Pharm. Bd. cix. S. 271.

$$\left\{\begin{matrix}C\,H_3\\ C\,O(N\,H_4)\end{matrix}\right. + C\begin{matrix}N'''\\ H\end{matrix} + H_2O + H\,Cl = \left\{\begin{matrix}C\,Me\,H(N\,H_2)\\ C\,O\,Ho\end{matrix}\right. + N\,H_4\,Cl:$$

Ammonic aldehyde. Hydrocyanic acid. Lactamic acid (alanin).

$$\left\{\begin{matrix}C\,Me\,H(N\,H_2)\\ C\,O\,Ho\end{matrix}\right. + N'''O\,Ho = \left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Ho\end{matrix}\right. + H_2O + N_2.$$

Lactamic acid (alanin). Nitrous acid. Lactic acid.

Not the least interesting reaction illustrative of the constitution of lactic acid, is the formation of this acid by the action of nascent hydrogen upon pyruvic acid, recently described by Wislicenus[*].

$$\left\{\begin{matrix}C\,Me\,O\\ C\,O\,Ho\end{matrix}\right. + H_2 = \left\{\begin{matrix}C\,Me\,H\,Ho\\ C\,O\,Ho\end{matrix}\right. .$$

Pyruvic acid. Lactic acid.

By an analogous reaction, glyoxylic acid, which we regard as the next lower homologue of pyruvic acid, has been transformed by Debus[†] into glycollic acid.

$$\left\{\begin{matrix}C\,H\,O\\ C\,O\,Ho\end{matrix}\right. + H_2 = \left\{\begin{matrix}C\,H_2\,Ho\\ C\,O\,Ho\end{matrix}\right. .$$

Glyoxylic acid. Glycollic acid.

In a similar manner it can be demonstrated that the above formula No. 2 expresses the constitution of paralactic acid, which belongs to the fifth or olefine division of these acids, $\left\{\begin{matrix}C\,\overset{+}{R}\,H\,Ho\\ (C\,H_2)_n(C\,O\,Ho)\end{matrix}\right.$, or $\left\{\begin{matrix}C\,\overset{+}{R}\,H\,Ho\\ (C\,H_2)_n\\ C\,O\,Ho\end{matrix}\right.$. That paralactic acid possesses this constitution is proved, first, by its production from cyanhydric glycol,

$$\left\{\begin{matrix}C\,H_2\,Ho\\ C\,H_2(C\,N)\end{matrix}\right. + K\,Ho + H_2O = \left\{\begin{matrix}C\,H_2\,Ho\\ C\,H_2\\ C\,O\,Ko\end{matrix}\right. + N\,H_3;$$

Cyanhydric glycol. Potassic paralactate.

and secondly, by its formation from phosgene gas and ethylene,

$$\left\{\begin{matrix}C\,H_2\\ C\,H_2\end{matrix}\right. + C\,O\,Cl_2 = \left\{\begin{matrix}C\,H_2\,Cl\\ C\,H_2(C\,O\,Cl)\end{matrix}\right. ;$$

Ethylene. Phosgene. Chloride of β chlorpropionyl.

$$\left\{\begin{matrix}C\,H_2\,Cl\\ C\,H_2(C\,O\,Cl)\end{matrix}\right. + 3K\,H\,O = \left\{\begin{matrix}C\,H_2\,Ho\\ C\,H_2(C\,O\,Ko)\end{matrix}\right. + 2K\,Cl + H_2O.$$

Chloride of β chlorpropionyl. Potassic paralactate.

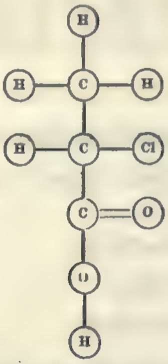
By the action of water upon the chloride of β chlorpropionyl, a body of the composition of chloropropionic acid results; but inasmuch as this body yields paralactic acid by ebullition with potash, whilst chloropropionic acid gives under the same circumstances lactic acid, it follows that the former chloro-acid must be isomeric, and not identical, with the latter. Now, although the formula of propionic acid does not admit of any isomer, yet that of chloropropionic acid does, as is seen in the following graphic formulæ.

---

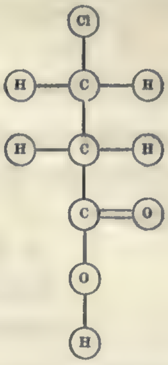
[*] Ann. der Chem. und Pharm. Bd. cxxvi. S. 225.

[†] *Ibid.* Bd. cxxvii. S. 145.

No. 1.



No. 2.



A comparison of these formulæ with those of lactic and paralactic acids (page 351) shows at a glance that No. 1 is the chloropropionic acid which yields lactic acid, whilst No. 2 is iso-chloropropionic acid, which, by the substitution of its chlorine by hydroxyl, must yield paralactic acid. By the action of nascent hydrogen, both isomeric chlorides will obviously produce the same propionic acid.

The cause of the isomerism of methyl-glycollic acid (No. 3, page 351) is so obvious as to require no further explanation. Proceeding to the next higher stage in the series, such is the rapid increase of isomerism, that we now encounter no less than eight possible isomers, all within the lactic family.

Normal.	Secondary.	Etheric normal.	
No. 1.	No. 2.	No. 3.	No. 4.
$\left\{\begin{array}{l}\mathrm{C\,Et\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,Me_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,H_2\,Eto}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Meo}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.

Normal olefine.			Etheric normal olefine.
No. 5.	No. 6.	No. 7.	No. 8.
$\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,H_2}\\ \mathrm{C\,H_2}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,Me\,H}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Ho}\\ \mathrm{C\,H_2}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,H_2\,Meo}\\ \mathrm{C\,H_2}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.

Of these acids, Nos. 1, 2, and 3 are known. No. 1 is oxybutyric acid; No. 2 is dimethoxalic acid, which is probably identical with STAEDELER'S acetonic acid*. On this assumption, the formation of the latter by the action of hydrocyanic and hydrochloric acids upon acetone is easily intelligible.

$$\underset{\text{Acetone.}}{\left\{\begin{array}{l}\mathrm{C\,H_3}\\ \mathrm{C\,O\,Me}\end{array}\right.}+\mathrm{C\,N'''\,H}+2\mathrm{H_2\,O}+\mathrm{H\,Cl}=\underset{\substack{\text{Acetonic or}\\ \text{dimethoxalic acid.}}}{\left\{\begin{array}{l}\mathrm{C\,Me_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.}+\mathrm{N^{v}\,H_4\,Cl}.$$

---

* Ann. der Chem. und Pharm. Bd. cxi. S. 320.

The properties of acetonic acid and its salts, as described by STAEDELER, agree well with those which we have observed in dimethoxalic acid and its compounds: both acids evolve an odour of acetone on being heated with potassic hydrate, and are decomposed without blackening by concentrated sulphuric acid, with evolution of much gas.

The third of the above formulæ is obviously that of HEINTZ's ethyl-glycollic acid*. The origin of WURTZ's butylactic acid, which was prepared by an analytical process, does not permit of any safe conclusion being drawn as to its constitution.

Of the possible acids containing five atoms of carbon, only one (the ethomethoxalic acid described above) is known†.

Of acids containing six atoms of carbon three are known, to which we assign the following formulæ:—

Leucic acid	$\begin{cases} \mathrm{C\,Bu\,H\,Ho} \\ \mathrm{C\,O\,Ho} \end{cases}$
Diethoxalic acid	$\begin{cases} \mathrm{C\,Et_2\,Ho} \\ \mathrm{C\,O\,Ho} \end{cases}$
Paraleucic acid	$\begin{cases} \mathrm{C\,H_2\,Ho} \\ \mathrm{C_4\,H_8} \\ \mathrm{C\,O\,Ho} \end{cases}$

The above formula for leucic acid is founded upon LIMPRICHT's‡ interesting reaction for the synthetical production of this acid from valerianic aldehyde and hydrocyanic acid.

KOLBE has shown that valerianic acid contains butyl; consequently valeraldehyde has the constitution expressed by the formula $\begin{cases} \mathrm{Bu} \\ \mathrm{C\,O\,H} \end{cases}$, and LIMPRICHT's reaction may therefore be explained by the following equation,

$$\underset{\text{Ammonic valeraldehyde.}}{\begin{cases} \mathrm{Bu} \\ \mathrm{C\,O\,(N\,H_4)} \end{cases}} + \mathrm{C}\begin{cases} \mathrm{N'''} \\ \mathrm{H} \end{cases} + \mathrm{H_2\,O} + \mathrm{H\,Cl} = \underset{\text{Leucin.}}{\begin{cases} \mathrm{C\,Bu\,H\,(N\,H_2)} \\ \mathrm{C\,O\,Ho} \end{cases}} + \mathrm{N^{v}\,H_4\,Cl}.$$

Such being the rational formula of leucin, its transformation into leucic acid by nitrous acid determines the constitution of leucic acid,

$$\underset{\text{Leucin.}}{\begin{cases} \mathrm{C\,Bu\,H\,(N\,H_2)} \\ \mathrm{C\,O\,Ho} \end{cases}} + \underset{\text{Nitrous acid.}}{\mathrm{N'''\,O\,Ho}} = \underset{\text{Leucic acid.}}{\begin{cases} \mathrm{C\,Bu\,H\,Ho} \\ \mathrm{C\,O\,Ho} \end{cases}} + \mathrm{H_2\,O} + \mathrm{N_2}.$$

We entertain no doubt of the isomerism of leucic and diethoxalic acids, although we have not yet been able to observe any substantial difference between them; both acids melt at nearly the same temperature (Leucic acid at 73° C., and diethoxalic acid at 74°·5° C.). Waage[*] states that zincic leucate requires 300 parts of water at 16° for its solution, whilst we find that zincic diethoxalate requires 302 parts at 16° C. Doubtless the study of the products of the transformation of these acids will reveal the difference existing between them: we are at present preparing leucic acid for this purpose. We have also mentioned in the experimental part of this paper that diethoxalic acid prepared from methylic diethoxalate yields a silver-salt which differs from that obtained with the acid from ethylic diethoxalate; and we have even noticed indications of a third synthesized isomer; but we reserve the further inquiry into the nature of these acids for a future communication.

---

* Pogg. Ann. cix. 331.

† Valerolactic acid, $\left(\begin{cases} \mathrm{C\,Pr\,H\,Ho} \\ \mathrm{C\,O\,Ho} \end{cases}\right)$, just discovered by FITTIG, forms a second. Its isomerism with ethomethoxalic acid is proved by its melting-point, which is 80° C., whilst ethomethoxalic acid fuses at 63° C.—April 29, 1866.

‡ Ann. der Ch. und Pharm. Bd. xciv. S. 243.

On the Proximate Analysis of the Acids of the Lactic Series.

The investigations recorded in the foregoing pages show that the division of acids of the lactic series which we have termed secondary acids, is derived from oxalic acid by the substitution of two atoms of monad alcohol radicals for one atom of oxygen in that acid. This substitution destroys one of the atoms of oxatyl in oxalic acid, thus reducing the latter from a dibasic to a monobasic acid. This theory of the structure of the secondary acids, so unmistakeably indicated by the mode of their formation, we have also extended to the normal acids, which are thus regarded as derived from oxalic acid, by the replacement of one atom of oxygen in the latter, either by hydrogen alone, as in glycollic acid, or by one atom of hydrogen and one of a monad alcohol radical:

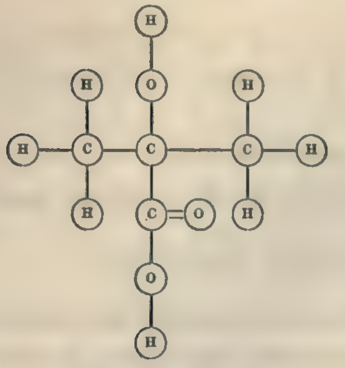
$$\begin{array}{ccc} \left\{\begin{array}{l}\mathrm{C\,O\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right. & \begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{array} & \left\{\begin{array}{l}\mathrm{C\,Me\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right. \\ \text{Oxalic acid.} & \text{Glycollic acid.} & \text{Lactic acid.} \end{array}$$

Hitherto we have advanced only synthetical evidence of this constitution; but the question presents itself, if the radicals indicated by our hypothesis really exist in these acids, can they not be again disentangled from the complex molecule, either in the condition in which they entered it, or, at all events, in the form of well recognized derivatives? Such analytical evidence, although possessing far less weight than synthetical, may still be of service as corroborative testimony. We will therefore show how such a proximate analysis of these acids may be accomplished, and for this purpose will first endeavour to demonstrate that if in a chain of carbon atoms any two be united by two bonds of each, the remaining atoms being united to each other by one bond only, the chain is more liable to rupture at the point of double junction than at any other. We have shown how in dimethoxalic acid a weak link of this kind can be developed[†]; for if dimethoxalic ether be treated with phosphorous chloride, it is transformed into ethylic methacrylate, the acid of which contains two atoms of carbon in the condition just indicated. The nature of this transformation and the link in the chain which is thus weakened are shown in the following graphic formulæ:—

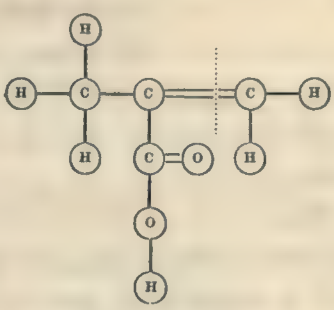
---

[*] Ann. der Ch. und Pharm. Bd. cxviii. S. 295.

[†] Journ. Chem. Soc. vol. xviii. p. 141.



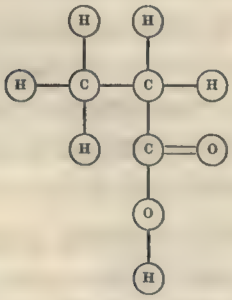
Dimethoxalic acid.



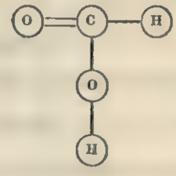
Methacrylic acid.

If methacrylic acid be now heated with potash, the acid molecule breaks up at the place indicated by the dotted line, with the production of propionic and formic acids:

$$\underset{\text{Methacrylic acid.}}{\left\{\begin{matrix}C\,Me\,Me''\\C\,O\,Ho\end{matrix}\right.} + 2K\,H\,O = \underset{\text{Potassic propionate.}}{\left\{\begin{matrix}C\,Me\,H_2\\C\,O\,Ko\end{matrix}\right.} + \underset{\text{Potassic formate.}}{\left\{\begin{matrix}H\\C\,O\,Ko\end{matrix}\right.} + H_2.$$



Propionic acid.



Formic acid.

Thus one of the atoms of methyl originally introduced into oxalic acid is now extracted in the shape of its well-known derivative, formic acid. We have proved by synthesis that propionic acid is methacetic acid, $\left\{\begin{matrix}C\,Me\,H_2\\C\,O\,Ho\end{matrix}\right.$; but it still remains to extract this second atom of methyl from it. For this purpose we might transform the propionic acid into chloropropionic acid, and the latter into ethylic lactate, by well-known processes, when, by repeating the reactions with phosphorous chloride and caustic potash above described, the second atom of methyl, like the first, ought to be eliminated as formic acid; but unfortunately the reaction with terchloride of phosphorus, although so easy with a secondary acid, fails when applied to a normal acid of the lactic series, and we are therefore driven to seek other means of obtaining the end in view. It is, however, only necessary to avail ourselves of the beautiful reactions of KOLBE* in order to extract the remaining atom of methyl in its integral form. Thus if the lactic acid, derived as above described, be submitted to the action of electrolytic oxygen, it is transformed into carbonic acid and aldehyde,

---

* Ann. der Chem. und Pharm. Bd. cxiii. S. 244.

$$\underset{\text{Lactic acid.}}{\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.} + \mathrm{O} = \underset{\text{Aldehyde.}}{\mathrm{C\,Me\,H\,O}} + \underset{\text{Carbonic acid.}}{\mathrm{C\,O\,Ho_2}}.$$

It will be observed that one of the atoms of oxatyl in the original oxalic acid $\left(\left\{\begin{array}{l}\mathrm{C\,O\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.\right)$ is here eliminated as the well-known derivative, carbonic acid.

The aldehyde thus obtained, and which contains the methyl sought for, must now be oxidized to acetic acid; and it then only remains to resort once more to electrolytic oxygen to liberate the methyl, together with the remaining atom of oxatyl, originally present in the oxalic acid,

$$2\underset{\text{Acetic acid.}}{\left\{\begin{array}{l}\mathrm{C\,H_3}\\ \mathrm{C\,O\,Ho}\end{array}\right.} + \mathrm{O_2} = \underset{\text{Methyl.}}{\left\{\begin{array}{l}\mathrm{C\,H_3}\\ \mathrm{C\,H_3}\end{array}\right.} + 2\mathrm{C\,O_2} + \mathrm{H_2\,O}.$$

We tabulate below the materials used in the synthesis of dimethoxalic acid side by side with the products obtained by the analysis of that acid:

Materials for Synthesis.		Results of Analysis.		
I.	II.	I.	II.	
$\left\{\begin{array}{l}\mathrm{C\,O\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.$.	$\left\{\begin{array}{l}\mathrm{C\,H_3}\\ \mathrm{C\,H_3}\end{array}\right.$.	$2\mathrm{C\,O\,Ho_2}$.	$\mathrm{C\,H_3}$.	$\mathrm{C\,O\,H\,Ho}$.
Oxalic acid.	Methyl.	Carbonic acid.	Methyl.	Formic acid.

In like manner the radicals contained in the other acids belonging to the normal and secondary divisions of the lactic series can be extracted, whilst it has already been proved by BUTLEROW * that etheric normal acids, when treated with concentrated solution of hydriodic acid, yield up, as iodide, the alcohol radical which in these acids is linked to carbon by oxygen; thus in the case of ethyl-lactic acid,

$$\underset{\text{Ethyl-lactic acid.}}{\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Eto}\\ \mathrm{C\,O\,Ho}\end{array}\right.} + \mathrm{H\,I} = \underset{\text{Lactic acid.}}{\left\{\begin{array}{l}\mathrm{C\,Me\,H\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.} + \underset{\text{Ethylic iodide.}}{\mathrm{Et\,I}}.$$

The olefine acids are as yet too little known to allow of their constitution being thus analytically investigated. These acids do not derive from oxalic acid by substitution alone, but by simultaneous addition of an olefine. They may, in fact, be regarded as standing somewhat in the same relation to the normal acids as the polyethylenic glycols occupy with regard to the normal glycols, as seen from the following comparison:—

$$\underset{\text{Glycol.}}{\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,H_2\,Ho}\end{array}\right.}. \qquad \underset{\text{Diethylenic glycol.}}{\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{O}\\ \mathrm{C_2\,H_4}\\ \mathrm{C\,H_2\,Ho}\end{array}\right.}. \qquad \underset{\text{Glycollic acid.}}{\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,O\,Ho}\end{array}\right.}. \qquad \underset{\text{Paralactic acid.}}{\left\{\begin{array}{l}\mathrm{C\,H_2\,Ho}\\ \mathrm{C\,H_2}\\ \mathrm{C\,O\,Ho}\end{array}\right.}.$$

---

* Ann. der Chem. und Pharm. Bd. cxviii. S. 326.

We beg to append the following summary of conclusions to which our investigations have conducted us:—

1. All acids of the lactic series are essentially monobasic.

2. These acids are of four species, viz. normal, secondary, normal olefine, and secondary olefine acids; and each of these species has its own etheric series of acids, in which the hydrogen of the hydroxyl contained in the positive or basylous constituent of the acid is replaced by a compound organic radical, either positive or negative.

3. The normal acids are derived from oxalic acid by the replacement of one atom of oxygen, either by two atoms of hydrogen, or by one atom of hydrogen and one atom of an alcohol radical.

4. The secondary acids are derived from oxalic acid by the replacement of one atom of oxygen by two atoms of monad alcohol radicals.

5. The olefine acids are derived from oxalic acid by a like substitution of two monad positive radicals for one atom of oxygen, with the insertion of an olefine or dyad radical ($C_n H_{2n}$) between the two atoms of oxatyl.

6. The acids of the lactic series stand to the acids of the acetic series in the very simple relation first pointed out by **Kolbe**, viz. that by the replacement, by hydrogen, of the hydroxyl, ethoxyl, &c., contained in the positive radical of an acid of the lactic series, that acid becomes converted into a member of the acetic series.

7. The acids of the lactic series stand in an almost equally simple relation to those of the acrylic series, as is seen on comparing the following formulæ:—

$$\left\{\begin{matrix}C(CH_3)H\,Ho\\ CO\,Ho\end{matrix}\right. \qquad\qquad \left\{\begin{matrix}C(CH_2)''H\\ CO\,Ho\end{matrix}\right.$$

Lactic acid. Acrylic acid.

XVI. *Fundamental Views regarding Mechanics.*

By Dr. J. Plücker, *of Bonn, For. Memb. R.S.*

Received May 29,—Read June 14, 1866.

Being encouraged by the friendly interest expressed by English geometricians, I have resumed my former researches, which have been entirely abandoned by me since 1846. While the details had escaped from my memory, two leading questions have remained dormant in my mind. The first question was to introduce right lines as elements of space, instead of points and planes, hitherto employed; the second question to connect, in mechanics, translatory and rotatory movements with each other by a principle in geometry analogous to that of reciprocity. I proposed a solution of the first question in the geometrical paper presented to the Royal Society. I met a solution of the second question, which in vain I sought for in Poinsot's ingenious theory of coupled forces, by pursuing the geometrical way. The indications regarding complexes of forces, given at the end of the "Additional Notes," involve it. I now take the liberty of presenting a new paper, intended to give to these indications the developments they demand, reserving for another communication a succinct abstract of the curious properties of complexes of right lines represented by equations of the *second* degree, and the simple analytical way of deriving them.

I.

1. We usually represent a force geometrically by a limited line, *i. e.* by means of two points (x', y', z') and (x, y, z), one of which (x', y', z') is the point acted upon by the force, while the right line passing through both points indicates its direction, and the distance between the two points its intensity. We may regard the six quantities

$$x-x', \quad y-y', \quad z-z', \quad yz'-y'z, \quad zx'-z'x, \quad xy'-x'y \quad . \; . \; . \; . \; . \quad (1)$$

as the six *coordinates of the force.* The six coordinates of a force represent its three projections on the three axes of coordinates OX, OY, OZ, and its three moments with regard to the same axes. By means of the three first coordinates the intensity P and the direction of the force; by means of the three last the resulting moment R and the direction of its axis; by the quotient $\frac{R}{P}$ the distance of the force from the origin, and therefore its position in space is determined.

Accordingly we may, as far as we do *not* regard the point acted upon by the force, replace its six coordinates (1) by

$$X, Y, Z, L, M, N. \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

But a force depending upon five constants only, there exists between these new coordinates an equation of condition, namely,

$$LX+MY+NZ=0, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

which indicates that the axis of the resulting moment R (the moment of the force with regard to the origin) is perpendicular to the direction of the force. In replacing the coordinates (2) by the equivalent primitive ones (1), the last equation becomes an identical one between the six point-coordinates x', y', z', x, y, z, and therefore is involved in the form given to the coordinates of the force.

The three last coordinates,

$$yz'-y'z, \quad zx'-z'x, \quad xy'-x'y,$$

remain unchanged in replacing x, y, z by $(x-x')$, $(y-y')$, $(z-z')$. Consequently we may substitute for them

$$Yz'-Zy', \quad Zx'-Xz', \quad Xy'-Yx'.$$

Thus, in omitting the accents of x', y', z',

$$X, \ Y, \ Z, \ Yz-Zy, \ Zx-Xz, \ Xy-Yx \quad . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

become the coordinates of the force. Now x, y, z denote the coordinates of *any* point of the line along which the force acts, its intensity and direction being given by X, Y, Z. The form of the new coordinates (4) involves the equation of condition (3).

2. If any number of given forces, represented by the symbols (x', y', z', x, y, z) or (X, Y, Z, L, M, N), act upon or pass through given points, according to the fundamental laws of statics, the *resulting effect* is obtained by adding the corresponding six coordinates of the forces

$$x-x', \quad y-y', \quad z-z', \quad yz'-y'z, \quad zx'-z'x, \quad xy'-x'y.$$

If the six sums thus obtained,

$$\Sigma(x-x'), \quad \Sigma(y-y'), \quad \Sigma(z-z'), \quad \Sigma(yz'-y'z), \quad \Sigma(zx'-z'x), \quad \Sigma(xy'-x'y), \quad . \quad (5)$$

or

$$\Sigma X, \quad \Sigma Y, \quad \Sigma Z, \quad \Sigma L, \quad \Sigma M, \quad \Sigma N, \quad . \; . \; . \; . \; . \; . \; . \quad (6)$$

satisfy the condition

$$\Sigma L.\Sigma X+\Sigma M.\Sigma Y+\Sigma N.\Sigma Z=0,$$

and therefore assume the form of the expressions (1), they are the six coordinates of a resulting force which replaces the given ones. In the general case I propose to call the cause producing the resulting effect *dyname*. The six sums (5) or (6), not satisfying the last equation of condition, may be regarded as the *six coordinates of the dyname*; the first three indicating the intensity and the direction of a force P, the last three the intensity of a moment and the direction of its axis.

In the case of a force (P) depending upon five constants, the moment and the direction of its axis are determined by means of these constants, *i. e.*, by means of

$$X, \ Y, \ Z, \ L, \ M, \ N, \quad . \; . \quad (2)$$

in admitting

$$LX+MY+NZ=0.$$

This equation not being admitted, the corresponding dyname (P, R) depends upon six *linear* constants (2), independent of each other. There is no relation admitted between the direction of the force (P) and the direction of the axis of the moment (R).

In denoting the angle between both directions by ϕ, we have

$$\frac{LX+MY+NZ}{PR}=\cos\phi. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

3. A linear complex of right lines* is represented by a homogeneous equation of the first degree,

$$A(x-x')+B(y-y')+C(z-z')+D(yz'-y'z)+E(zx'-z'x)+F(xy'-x'y)\equiv\Omega=0, \quad . \quad (8)$$

between the six line-coordinates

$$(x-x'),\ (y-y'),\ (z-z'),\ (yz'-y'z),\ (zx'-z'x),\ (xy'-x'y), \quad . \quad (1)$$

regarded as variables. These quantities are simultaneously the coordinates of a force. Let us replace the homogeneous equation (8) by the general one of the first degree,

$$\Omega-1\equiv\Xi=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Forces the coordinates of which satisfy this equation constitute a *linear complex of forces.* The six coordinates of the two points (x', y', z') and (x, y, z) by which the force is determined may likewise be regarded as variables replacing the coordinates (1).

In order to get the forces of the complex Ξ acting upon any given point of space (x', y', z'), we must regard the coordinates of this point as constant. On this supposition the equation of the complex, which may be written thus,

$$\left.\begin{aligned} &(A+Fy'-Ez')x\\ &+(B-Fx'+Dz')y\\ &+(C+Ex'-Dy')z\\ =&Ax'+By'+Cz'+1,\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

represents a *plane.* Therefore the geometrical locus of the second points (x, y, z), by which the forces acting on the given point (x', y', z') are determined, is a plane. This plane may be called *conjugate* to the point acted upon.

In a linear complex there are acting upon each point of space forces in all directions, the intensity of each force being the segment on its direction between the point acted upon and its conjugate plane.

4. In supposing the forces, and consequently their coordinates, to be infinite, the equation (9) of the complex Ξ becomes

$$\Omega=0.$$

This equation, therefore, representing a complex of right lines, indicates the position of those forces of the complex Ξ the intensity of which is infinite.

---

* See geometrical Paper, p. 734, Philosophical Transactions, 1865.

From my geometrical paper* we deduce that, by a proper transformation of coordinates, the function Ω may be reduced, in putting

$$\mathrm{C}'=\frac{\mathrm{AD}+\mathrm{BE}+\mathrm{CF}}{\sqrt{\mathrm{D}^2+\mathrm{E}^2+\mathrm{F}^2}}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (11)$$

$$\mathrm{F}'=\sqrt{\mathrm{D}^2+\mathrm{E}^2+\mathrm{F}^2}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (12)$$

to the simple expression

$$\mathrm{F}'(xy'-x'y)+\mathrm{C}'(z-z').$$

Accordingly the general equation of the complex Ξ assumes the form

$$\mathrm{F}'(xy'-x'y)+\mathrm{C}'(z-z')=1; \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (13)$$

and in putting

$$\frac{\mathrm{AD}+\mathrm{BE}+\mathrm{CF}}{\mathrm{D}^2+\mathrm{E}^2+\mathrm{F}^2}=\frac{\mathrm{C}'}{\mathrm{F}'}=k, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

$$\frac{1}{\sqrt{\mathrm{D}^2+\mathrm{E}^2+\mathrm{F}^2}}=\frac{1}{\mathrm{F}'}=kk', \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (15)$$

may be written thus,

$$(xy'-x'y)+k(z-z'-k')=0. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (16)$$

There is in a complex of right lines an axis round which it may revolve, and along which it may be displaced parallel to itself, without being changed. After this double movement each line of the complex occupies the place formerly taken by another of its lines. After the transformation of coordinates, the axis of the complex Ω, which may be likewise called *the axis of the complex of forces* Ξ, coincides with OZ; the origin being arbitrarily chosen on OZ, and the axes OX and OY being any two right lines drawn through this point perpendicular to OZ and to each other.

The form of the last equation shows that a linear complex of forces Ξ, like the corresponding complex of lines Ω, *remains unaltered when rotating round its axis or moving parallel to it*, i. e. each force of the complex in its new direction and the new position of the point upon which it acts, continues to belong to the complex in retaining its intensity.

5. Let

$$\Xi\equiv\Omega-1=0, \quad \Xi'\equiv\Omega'-1=0 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (17)$$

represent any two linear complexes of forces. Congruent forces of both complexes, the coordinates of which satisfy simultaneously both equations (17), constitute a *congruency of forces*. Their coordinates satisfy likewise the equation

$$\Xi-\Xi\equiv\Omega-\Omega'=0, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (18)$$

derived from the primitive ones by eliminating their constant term. Hence

In a congruency, the forces act along right lines constituting a linear complex.

The forces of a congruency belonging simultaneously to two complexes, those of them passing through a given point meet the right line along which the two conjugate planes of the point in the two complexes intersect each other.

---

* Geometrical Paper, p. 746.

In a congruency, there act on every point of space an infinite number of forces along right lines constituting a plane, their intensity being given by the distance of the point acted upon from the points of a given right line confined within that plane.

6. Let

$$\Xi\equiv\Omega-1=0,\quad \Xi'\equiv\Omega'-1=0,\quad \Xi''\equiv\Omega''-1=0 \quad . \; . \; . \; . \; . \; . \quad (19)$$

represent any three linear complexes of forces. Forces, the coordinates of which satisfy simultaneously the three equations, constitute a *double congruency of forces.* Hence we derive immediately the following theorem:—

In a double congruency of forces there is passing through each point of space one single force of given direction and given intensity.

The intensity of the force is equal to the distance between the point acted upon and the point where the three planes conjugate in the three complexes meet.

7. We may derive from the equations (19) the two following:

$$\Omega-\Omega'=0,\quad \Omega-\Omega''=0. \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (20)$$

The coordinates of forces of the double congruency satisfy likewise both equations (20), the system of which represents a congruency of right lines.

The forces of a double congruency act upon right lines which constitute a congruency.

I proved in the geometrical paper that all lines of a congruency intersect two given lines. Hence

All forces constituting a double congruency meet two fixed lines.

8. In following our way we meet congruent forces of four complexes constituting a *threefold congruency.* Their coordinates satisfy simultaneously the equations of the four complexes,

$$\Xi=0,\quad \Xi'=0,\quad \Xi''=0,\quad \Xi'''=0, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (21)$$

as well as the equations

$$\Xi-\Xi'=0,\quad \Xi-\Xi''=0,\quad \Xi-\Xi'''=0 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (22)$$

derived from them, the system of which represents a rectilinear hyperboloid. Hence

The forces belonging to a threefold congruency act along the generatrices of a hyperboloid*, the points of which are the points acted upon. There are conjugated to such a point in the four complexes of forces (21) four planes meeting in another point of the same generatrix. The distance between the two points represents the intensity of the corresponding force, varying if the point acted upon move on the generatrix.

9. There are only two forces belonging simultaneously to five complexes, *i. e.* there are two right lines, on each point of which one single force of given intensity acts along its direction. Indeed by means of the five equations of the complexes, we may determine, by elimination, five of the six coordinates, which, for simplicity, may be denoted

---

* Geometrical Paper, p. 757.

by X, Y, Z, L, M, N, as linear functions of the sixth. Accordingly the equation of condition,

$$LX+MY+NZ=0,$$

may be transformed into an equation of the second degree with regard to the sixth coordinate.

10. In the complexes hitherto considered, the forces acting along a right line vary in intensity when the point acted upon moves on that line. According to the more usual notion there is, along a given line, one single force of given intensity acting upon any point of the line. In order to represent complexes of such forces, we replace the coordinates (1), made use of hitherto, either by the coordinates

$$X,\ Y,\ Z,\ L,\ M,\ N \quad \dots\dots\dots\dots \quad (2)$$

in admitting the equation of condition

$$LX+MY+NX=0, \quad \dots\dots\dots \quad (3)$$

or by the coordinates

$$X,\ Y,\ Z,\ Yz-Zy,\ Zx-Xz,\ Xy-Yx. \quad \dots \quad (4)$$

In both systems of coordinates there is no trace left of the point acted upon by the force. The same coordinates belong to right lines, and the homogeneous equation

$$AX+BY+CZ+DL+EM+FN\equiv\Phi=0 \quad \dots\dots\dots \quad (23)$$

represents the same linear complex of lines which was formerly represented by the equation

$$\Omega=0.$$

Put

$$\Psi\equiv\Phi-1=0. \quad \dots\dots\dots\dots\dots \quad (24)$$

All forces, the coordinates of which satisfy this equation, constitute such a new complex. It is essential not to confound such complexes with the former ones.

11. The coordinates x, y, z of any point on the direction of a force are introduced in making use of the coordinates (4). Accordingly the equation of the complex Ψ becomes

$$AX+BY+CZ+D(Yz-Zy)+E(Zx-Xz)+F(Xy-Yx)=0. \quad \dots \quad (25)$$

If

$$Yz=Zy,$$
$$Zx=Xz,$$
$$Xy=Yx,$$

the corresponding forces pass through the origin; for these forces, belonging to the complex Ψ, we obtain

$$AX+BY+CZ=0.$$

Let

$$x=az, \quad y=bz$$

indicate the direction of any of these forces, we obtain

$$X=aZ, \quad Y=bZ,$$

whence

$$Z=\frac{1}{Aa+Bb+C},$$

and the intensity of the force

$$P=\frac{\sqrt{1+a^2+b^2}}{Aa+Bb+C}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

If the system of coordinates is displaced parallel to itself, any point (x_0, y_0, z_0) becoming the new origin, X, Y, Z remain unaltered, while x, y, z are replaced by $(x+x_0)$, $(y+y_0)$, $(z+z_0)$. Accordingly the equation (25) is transformed into the following one:

$$AX+BY+CZ+D\big(Y(z+z_0)-Z(y+y_0)\big)+E\big(Z(x+x_0)-X(z+z_0)\big)+F\big(X(y+y_0)-Y(x+x_0)\big)=1.$$

In putting x, y, $z=0$, the following relation

$$(A-Ez_0+Fy_0)X+(B+Dz_0-Fx_0)Y+(C-Dy_0+Ex_0)Z=1 \quad . \quad . \quad . \quad (27)$$

is obtained between the coordinates of forces passing through the new origin. Let, in the primitive system of coordinates,

$$x-x_0=a(z-z_0),$$
$$y-y_0=b(z-z_0)$$

indicate the direction of any such force, its intensity is

$$P=\frac{\sqrt{1+a^2+b^2}}{(A-Ez_0+Fy_0)a+(B+Dz_0-Fx_0)b+(C-Dy_0+Ex_0)}$$
$$=\frac{1}{(A-Ez_0+Fy_0)\cos\alpha+(B+Dz_0-Fx_0)\cos\beta+(C-Dy_0+Ex_0)\cos\gamma}$$
$$=\frac{1}{A\cos\alpha+B\cos\beta+C\cos\gamma+D(z_0\cos\beta-y_0\cos\gamma)+E(x_0\cos\gamma-z_0\cos\alpha)+F(y_0\cos\alpha-x_0\cos\beta)}.$$

There is one force passing simultaneously through both origins, determined by the relations

$$x_0 : y_0 : z_0 = X : Y : Z,$$

by which the last expression for P is reduced to the former (26). The force acting along the same right line is the same. All other forces of the complex Ψ passing through the primitive origin, when displaced parallel to themselves, so as to meet the new origin, generally change their intensity. This intensity is not changed if, the direction of the force remaining the same,

$$Ez_0=Fy_0,$$
$$Dz_0=Fx_0,$$
$$Dy_0=Ex_0,$$

i. e. if the new origin describes what we may call a diameter of the complex. We do not enter into any detail, because the results thus obtained would be involved in the following developments.

12. Indeed, in so transforming the arbitrary system of rectangular coordinates—as we did in the case of complexes Ξ—that the new axis OZ coincides with the axis of the complex of lines Φ, the equation (24) is replaced by the equation

$$N+k(Z-k')=0, \quad \ldots \ldots \ldots \ldots \quad (28)$$

k and k' retaining their signification of No. 4, and may be written thus,

$$P(\delta\cos\nu+k\cos\gamma)=kk', \quad \ldots \ldots \ldots \ldots \quad (29)$$

in denoting by γ and ν the angles which the directions of the forces and of the axes of their moments make with OZ, and by δ the distances of the lines along which the forces act from the origin. Hence we conclude that the intensities of forces of the complex are the same if

$$\delta\cos\nu+k\cos\gamma=\text{const.} \quad \ldots \ldots \ldots \ldots \quad (30)$$

That is especially the case if the line along which a force acts be displaced parallel to OZ or turned round it. Hence

A force of a complex Ψ which, while retaining its intensity, is displaced parallel to the axis of the complex or turns round it, in all its new positions continues to belong to the complex.

13. The lines along which congruent forces of any two complexes Ψ act constitute a linear complex of lines. The congruent forces of three complexes Ψ are directed along lines of a congruency, and consequently meet two fixed lines, *there is one force passing through each point of space, and one confined within each plane traversing it.* The congruent forces of four complexes Ψ are directed along the generatrices of a hyperboloid, their intensity only varying from one generatrix to another. Finally, five complexes Ψ meet along two forces (either real or imaginary).

14. A *dyname*, determined by its six *linear* coordinates,

$$X, Y, Z, L, M, N, \quad \ldots \quad (2)$$

represents the effect produced by two forces not intersecting each other, the points acted upon not being regarded. The six sums of the corresponding coordinates of both forces are the six coordinates of the dyname. Reciprocally, a dyname, the coordinates of which are given, may be resolved into equivalent pairs of forces; but a dyname depending upon six, a pair of forces upon ten constants, four of these ten constants may be chosen arbitrarily. Let

$$\begin{array}{llllll} \mathrm{x}, & \mathrm{y}, & \mathrm{z}, & \mathrm{l}, & \mathrm{m}, & \mathrm{n}, \\ \mathrm{x}', & \mathrm{y}', & \mathrm{z}', & \mathrm{l}', & \mathrm{m}', & \mathrm{n}', \end{array}$$

be the coordinates of such a pair of forces. The following relations,

$$\mathrm{x}+\mathrm{x}'=X, \quad \mathrm{y}+\mathrm{y}'=Y, \quad \mathrm{z}+\mathrm{z}'=Z,$$
$$\mathrm{l}+\mathrm{l}'=L, \quad \mathrm{m}+\mathrm{m}'=M, \quad \mathrm{n}+\mathrm{n}'=N,$$

take place, and besides the following two:

$$\textsc{lx}+\textsc{my}+\textsc{nz}=0,$$
$$\textsc{l}'\textsc{x}'+\textsc{m}'\textsc{y}'+\textsc{n}'\textsc{z}'=0.$$

The last equation may be developed thus,

$$(L-\textsc{l})(X-\textsc{x})+(M-\textsc{m})(Y-\textsc{y})+(N-\textsc{n})(Z-\textsc{z})=0,$$

and reduced by means of the preceding one as follows:

$$\left.\begin{aligned} &L\textsc{x}+M\textsc{y}+N\textsc{x} \\ &+X\textsc{l}+Y\textsc{m}+Z\textsc{n} \\ &=LX+MY+NZ. \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (31)$$

If the coordinates of the dyname be regarded as constant, $\textsc{x}$, $\textsc{y}$, $\textsc{z}$, $\textsc{l}$, $\textsc{m}$, $\textsc{n}$ as variable, this equation represents a linear complex of forces. By interchanging the two forces we meet again the same equation. Hence

A dyname may be resolved into pairs of forces, the forces of all pairs constitute a linear complex.

We must desist from entering into any further detail.

15. Any number of dynames being given, the coordinates of the resulting dyname are obtained by adding the coordinates of the given ones. If the six sums are equal to zero, equilibrium exists.

16. Dynames (P, R) the coordinates of which satisfy the linear equation

$$\Psi=AX+BY+CZ+DL+EM+FN-1=0, \quad . \; . \; . \; . \; . \; . \qquad (32)$$

constitute a *complex of dynames.* In supposing P and R, and therefore the coordinates of the dyname, infinite, the last equation becoming homogeneous,

$$AX+BY+CZ+DL+EM+FN=0 \quad . \; . \; . \; . \; . \; . \; . \qquad (33)$$

represents a *complex of two variable lines.*

Dynames the coordinates of which satisfy simultaneously two linear equations,

$$\Psi=0, \quad \Psi'=0,$$

constitute a *congruency of dynames.* In eliminating the constant term, the resulting equation,

$$\Psi-\Psi'=0,$$

represents a complex of two variable lines.

II.

1. We determine a force producing repulsion or attraction by means of two points in space, one of which is the point acted upon. In quite an analogous way we may represent a rotation, or the force producing it, by means of two planes,

$$\left.\begin{aligned} t'x+u'y+v'z&=1, \\ tx+uy+vz&=1, \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (1)$$

the coordinates of which are t', u', v' and t, u, v, one of the two planes (t', u', v') being acted upon. The right line, along which both planes meet, is the axis of rotation. The plane acted upon (t', u', v') may in a double way turn round the axis of rotation in order to coincide with the second plane (t, u, v); but there is no more ambiguity in admitting that during the rotation the rotating-plane does not pass through the origin, and consequently its coordinates do not become infinite. (In an analogous way we determine the distance of two points.)

Let us regard the six quantities,

$$t-t', \quad u-u', \quad v-v', \quad uv'-u'v, \quad vt'-v't, \quad tu'-t'u, \quad \ldots \quad (2)$$

as the six coordinates of the rotatory force, as they are the six coordinates of its axis of rotation. As far as we do not regard the plane acted upon by the rotatory force, we may replace them by the following six,

$$\mathfrak{X}, \quad \mathfrak{Y}, \quad \mathfrak{Z}, \quad \mathfrak{L}, \quad \mathfrak{M}, \quad \mathfrak{N}, \quad \ldots \quad (3)$$

in admitting the equation of condition,

$$\mathfrak{L}\mathfrak{X}+\mathfrak{M}\mathfrak{Y}+\mathfrak{N}\mathfrak{Z}=0. \quad \ldots \quad (4)$$

Finally, we may write the coordinates (2) in the following way,

$$\mathfrak{X}, \quad \mathfrak{Y}, \quad \mathfrak{Z}, \quad \mathfrak{Y}v-\mathfrak{Z}u, \quad \mathfrak{Z}t-\mathfrak{X}v, \quad \mathfrak{X}u-\mathfrak{Y}t, \quad \ldots \quad (5)$$

(t, u, v) being *any* plane passing through the axis of rotation.

2. The notation of the preceding number being rather unusual, it appears suitable to introduce a few remarks before proceeding.

In referring to the "Additional Notes" of the geometrical paper *, we get

$$\mathrm{X} : \mathrm{Y} : \mathrm{Z} = \cos\lambda : \cos\mu : \cos\nu, \quad \ldots \quad (6)$$

$$\mathrm{L} : \mathrm{M} : \mathrm{N} = \cos\alpha : \cos\beta : \cos\gamma; \quad \ldots \quad (7)$$

and in putting

$$\mathfrak{X}^2+\mathfrak{Y}^2+\mathfrak{Z}^2=\mathfrak{P}^2, \quad \ldots \quad (8)$$

$$\mathfrak{L}^2+\mathfrak{M}^2+\mathfrak{N}^2=\mathfrak{R}^2, \quad \ldots \quad (9)$$

there results

$$\mathfrak{R}=\frac{\mathfrak{P}}{\delta}. \quad \ldots \quad (10)$$

Here the angles made by the axis of rotation with the three axes of coordinates OX, OY, OZ are denoted by λ, μ, ν; the angles made with the same axes of coordinates by the right line perpendicular to the plane containing the origin and the axis of rotation by α, β, γ; δ denotes the distance of the axis of rotation from the origin; finally, let us call P the *intensity* of the rotatory force, R its moment, and the right line passing through the origin and making, with the three axes of coordinates, the angles α, β, γ, *he axis of the moment.*

---

* Philosophical Transactions, 1865, p. 776.

3. Both the intensity (P) and the moment (R) of a rotatory force depend only upon the position of the origin; they do not depend upon the direction of the axes of coordinates. Indeed p and p' denoting the distance of the planes (t, u, v), (t', u', v'), by means of which a rotatory force $(t'u'v', tuv)$ is determined, from the origin, and ω the angle between the planes, we have

$$\mathfrak{P}^2=(t-t')^2+(u-u')^2+(v-v')^2=\frac{1}{p^2}+\frac{1}{p'^2}-\frac{2\cos\omega}{pp'}. \quad . \quad . \quad . \quad . \quad (11)$$

Again, the intensity (P) being given according to (10), the moment of the rotatory force (R) remains the same when the axis of rotation gets into any other position, as long as δ, the distance of the axis from the origin, does not change, and in particular when the axis of rotation turns round the axis of the moment.

4. The six coordinates of an ordinary force $(x'y'z, xyz)$ remain the same when, the mutual distance of the two points $(x'y'z')$ and $(x; y, z)$ not being altered, the point (x', y', z') acted upon moves along the direction of the force. So do the six coordinates of a rotatory force $(t'u'v', tuv)$ when, P remaining the same, the plane (t', v', v') acted upon rotates round the axis of rotation. A repulsive or attractive force may act on each point of its direction, a rotatory force on each plane passing through its axis. Let

$$t'x+u'y+v'z-1\equiv s'=0,$$
$$tx+uy+vz-1\equiv s=0,$$

be the equations of the planes (t', u', v') and (t, u, v) by which a rotatory force is determined. In denoting by μ' and μ any two arbitrary constants, the following equations,

$$s-\mu's'=0,$$
$$s'-\mu s=0,$$

represent any two new planes passing through the axis of rotation. Let (t'_0, u'_0, v'_0) and (t_0, u_0, v_0) be the corresponding symbols of the new planes. The first of the two planes, depending upon the constant μ', may be regarded as any plane acted upon by the rotatory force, and accordingly the second plane, depending upon the constant μ, may be determined so that the intensity of the rotatory force, and therefore its moment, shall not be changed. In this supposition

$$t-t'=t_0-t'_0,$$
$$u-u'=u_0-u'_0,$$
$$v-v'=v_0-v'_0,$$

whence we derive

$$\mu+\mu'=2.$$

There are three values of μ',

$$\frac{t}{t'}, \quad \frac{u}{u'}, \quad \frac{v}{v'},$$

indicating planes acted upon parallel to OX, OY, OZ; let G, H, I be the points in which the corresponding second plane meets the same axes. If any other plane passing through the axis of rotation and intersecting the axes of coordinates in the points G′, H′, I′ is taken as the plane acted upon by the rotatory force, the corresponding second plane intersects the same axes in three points G_1, H_1, I_1, such that the three couples of points,

$$\begin{array}{l} O, G \text{ and } G', G, \\ O, H \text{ and } H', H, \\ O, I \text{ and } I', I, \end{array}$$

constitute, on the three axes of coordinates, three systems of harmonic points.

5. If any force be given, its intensity (P) is quite independent of the axes of rectangular coordinates, which may be arbitrarily chosen, but its moment (R) depends upon the choice of the origin. The point upon which the force acts, if free, is impelled along a given line. If the point acted upon be attached to any fixed point, the translatory movement is changed into a rotatory one. Any plane perpendicular to the direction of the force revolves, if one of its points be fixed, round an axis, confined within the plane, passing through the fixed point and perpendicular to the direction of the force. This axis is the axis of the moment of the force with regard to the fixed point which in the considerations of Part I. was the origin of coordinates. The cause producing the double effect is called *force*. This definition involves that the direction of the force and the direction of the axis of its moment be perpendicular to each other. If there is a moment, the axis of which is not perpendicular to the direction of the translatory movement produced, the cause of it is no more a mere force: we called it a *dyname*.

If any rotatory force be given, both the intensity of the force and the intensity of its moment are independent of the direction of the axes of coordinates, only both depend upon the position of the origin (3). A plane perpendicular to the axis of rotation remains the same during the revolution. If there is another invariable plane, *i. e.* a plane not able to turn round any axis confined within it, and therefore, this axis being infinitely distant, not able to be displaced parallel to itself, the revolution is stopped and transformed into a translatory movement of the plane acted upon. Indeed the intersection of the two invariable planes becoming an invariable line, able only to move along its own direction, the plane acted upon and all the planes connected with it are displaced along the invariable line. The movement along this direction may be decomposed into three, along the axes of coordinates. The cause producing the double movement is called *rotatory force*. If the condition that both axes (of rotation and of translation) are perpendicular to each other be *not* fulfilled, we shall call it *a* (*rotatory*) *dyname*. If any point of the line, moveable only along its own direction, be fixed, it endures a pressure along that line which is proportional to the translatory movement, and may be likewise decomposed along the axes of coordinates.

6. Let us, in order to confirm in the analytical way the general views of the last number, consider a rotation the axis of which is confined in the plane XY, and within this plane directed parallel to OX. Let us admit, too, that the plane acted upon, passing through the axis of rotation, is parallel to OZ. Under these conditions, the symbol

for the rotation being $(tu0, tuv)$, its coordinates are

$$0,\quad 0,\quad v,\quad uv,\quad 0,\quad 0.$$

Accordingly OZ is the axis of the moment; we obtain

$$\mathfrak{P}=v,\quad \mathfrak{R}=uv,\quad \delta=\frac{1}{u};$$

and in putting

$$\delta v=-\tan\omega,$$

we have

$$\mathfrak{P}=-\frac{\tan\omega}{\delta},\quad \mathfrak{R}=-\frac{\tan\omega}{\delta^2};$$

Here ω denotes the *angle of rotation*, taken in starting from the plane acted upon in the direction from OZ to OX. In passing to infinitesimals, the last equation becomes

$$\mathfrak{P}=-\frac{\omega}{\delta},\quad \mathfrak{R}=-\frac{\omega}{\delta^2}.$$

7. When two rotations take place simultaneously, there is a resulting one in the case only where both axes of rotation are confined within the same plane. Let

$$\begin{array}{llllll}\mathfrak{X}, & \mathfrak{Y}, & \mathfrak{Z}, & \mathfrak{Y}v-\mathfrak{Z}u, & \mathfrak{Z}t-\mathfrak{X}v, & \mathfrak{X}u-\mathfrak{Y}t, \\ \mathfrak{X}', & \mathfrak{Y}', & \mathfrak{Z}', & \mathfrak{Y}'v'-\mathfrak{Z}'u', & \mathfrak{Z}'t'-\mathfrak{X}'v', & \mathfrak{X}'u'-\mathfrak{Y}'t',\end{array}$$

be the six coordinates of the rotation, (t, u, v) and (t', u', v') being any two planes containing their axes. If both axes be confined in the same plane, t', u', v' may be replaced by t, u, v. In this supposition, by adding the corresponding coordinates, we get

$$\mathfrak{X}+\mathfrak{X}',\quad \mathfrak{Y}+\mathfrak{Y}',\quad \mathfrak{Z}+\mathfrak{Z}',$$
$$(\mathfrak{Y}+\mathfrak{Y}')v-(\mathfrak{Z}+\mathfrak{Z}')u,\quad (\mathfrak{Z}+\mathfrak{Z}')t-(\mathfrak{X}+\mathfrak{X}')v,\quad (\mathfrak{X}+\mathfrak{X}')u-(\mathfrak{Y}+\mathfrak{Y}')t.$$

These six sums are the coordinates of a new rotation, the axis of which is within the same plane (t, u, v). Here the three equations of condition,

$$\mathfrak{X}+\mathfrak{X}'=0,\quad \mathfrak{Y}+\mathfrak{Y}'=0,\quad \mathfrak{Z}+\mathfrak{Z}'=0,$$

which render the six coordinates of the resulting rotation equal to zero, are sufficient to express that equilibrium exists.

In the general case, where both axes of rotation are not confined within the same plane, the six sums of coordinates

$$\mathfrak{X}+\mathfrak{X}',\quad \mathfrak{Y}+\mathfrak{Y}',\quad \mathfrak{Z}+\mathfrak{Z}',$$
$$(\mathfrak{Y}v+\mathfrak{Y}'v')-(\mathfrak{Z}u+\mathfrak{Z}'u'),\quad (\mathfrak{Z}t+\mathfrak{Z}'t')-(\mathfrak{X}v+\mathfrak{X}'v'),\quad (\mathfrak{X}u+\mathfrak{X}'u')-(\mathfrak{Y}t+\mathfrak{Y}'t'),$$

are the coordinates of a *dyname*. When equilibrium exists we get, in order to express that all resulting effect be destroyed, six equations of condition by putting the six coordinates equal to zero.

8. By generalizing, the following theorem is immediately derived:—

Any number of rotatory forces acting simultaneously, the coordinates of the resulting rotatory force, if there is such a force, if there is not, the coordinates of the resulting *rotatory dyname, are obtained by adding the coordinates of the given rotatory forces. In the case of equilibrium the six sums obtained are equal to zero.*

Accordingly the given rotatory forces (or rotations) being represented by the general symbols $(t'u'v', tuv)$, their coordinates are

$$t-t', \quad u-u', \quad v-v', \quad uv'-u'v, \quad vt'-v't, \quad tu'-t'u,$$

and

$$\Sigma(t-t'), \quad \Sigma(u-u'), \quad \Sigma(v-v'), \quad \Sigma(uv'-u'v), \quad \Sigma(vt'-v't), \quad \Sigma(tu'-t'u),$$

the coordinates of the resulting force or dyname.

9. The theorem of the last number embraces the statics of rotatory forces as the analogous theorem of Part I., No. 2 involves the statics of ordinary forces. We gave this theorem as the expression of known statical laws. Inversely we might, having previously stated the theorem in a direct way, deduce from it the theorems of statics. Indeed the theorem follows from the mere consideration that the corresponding coordinates of forces,—the three first of which, X, Y, Z, are represented by segments of right lines, the three last, L, M, N, by areas,—indicating homogeneous quantities, may be added, and after addition the sums obtained interpreted in the same way.

The following numbers will show the application of the new theorem, and of its inverse, regarding decomposition of rotatory forces or dynames.

10. Any number n of rotatory forces acting simultaneously on the same plane (t', u', v') may be represented by symbols, t', u', v' being the same in all. By adding their coordinates, the six sums obtained (2) may be written thus,

$$\begin{array}{lll} \Sigma t-nt', & \Sigma u-nu', & \Sigma v-nv', \\ \Sigma u.v'-\Sigma v.u', & \Sigma v.t'-\Sigma t.v', & \Sigma t.u'-\Sigma u.t'; \end{array}$$

or in putting

$$\Sigma t=n\vartheta, \qquad \Sigma u=n\varrho, \qquad \Sigma v=n\sigma,$$

thus

$$\begin{array}{lll} n(\vartheta-t'), & n(\varrho-u'), & n(\sigma-v'), \\ n(\varrho v'-\sigma u'), & n(\sigma t'-\vartheta v'), & n(\vartheta u'-\varrho t'). \end{array}$$

These expressions are the coordinates of the resulting rotatory force; ϑ, ϱ, σ are the coordinates of a plane, replacing in the theory of rotation the centre of gravity, which may be called the *central plane of* the given planes (t, u, v), by which, the plane acted upon (t', u', v') being given, the rotatory forces are determined. The resulting axis of rotation is the intersection of the given plane (t', u', v') and the central plane $(\vartheta, \varrho, \sigma)$. The intensity of the resulting force is

$$n\sqrt{(\vartheta-t')^2+(\varrho-u')^2+(\sigma-v')^2}.$$

In the case of equilibrium,

$$\vartheta=t', \quad \varrho=u', \quad \sigma=v',$$

i. e. *the central plane is congruent with the plane acted upon by the given rotatory forces.*

11. A rotatory force,

$$(t'u'v', tuv),$$

may be decomposed into three,

$$(t'u'v',\ t'u'v),\quad (t'u'v',\ t'uv'),\quad (t'u'v',\ tu'v')\text{*},$$

the six coordinates of which are

$$\begin{array}{cccccc}
0 & 0 & v-v' & -u'(v-v') & t'(v-v') & 0 \\
0 & u-u' & 0 & v'(u-u') & 0 & -t'(u-u') \\
t-t' & 0 & 0 & 0 & -v'(t-t') & u'(t-t').
\end{array}$$

In adding these coordinates, we get

$$t-t',\quad u-u',\quad v-v',\quad uv'-u'v,\quad vt'-v't,\quad tu'-t'u,$$

i. e. the coordinates of the recomposed given rotatory force.

The three axes of the decomposed rotatory forces are the intersections of the plane acted upon by (t', u', v'), with the three planes of coordinates XY, XZ, YZ, constituting a triangle, the angles of which fall into the three axes of coordinates.

The given rotatory force is thus decomposed into three equivalent ones, the intensity of which is

$$\mathfrak{P}\cos\nu=(v-v')=\mathfrak{X},$$
$$\mathfrak{P}\cos\mu=(u-u')=\mathfrak{Y},$$
$$\mathfrak{P}\cos\lambda=(t-t')=\mathfrak{Z}.$$

In putting

$$\sqrt{t'^2+u'^2}=\frac{1}{r},$$

$$\sqrt{t'^2+v'^2}=\frac{1}{q},$$

$$\sqrt{u'^2+v'^2}=\frac{1}{p},$$

r, q, p denote the distances within the planes XY, XZ, YZ of the axes of the decomposed forces from the origin, and

$$\frac{\mathfrak{Z}}{r},\quad \frac{\mathfrak{Y}}{q},\quad \frac{\mathfrak{X}}{p}$$

represent the three corresponding moments. These moments do not change if, within the planes of coordinates, the axes of rotation revolve round the origin, and especially become parallel to an axis of coordinates; $\frac{\mathfrak{Z}}{r}$ for instance, if the corresponding axis become parallel to OY or OZ, is equivalent to one single coordinate $\frac{v-v'}{r}$, replacing both former ones—$u'(v-v')$ and $t'(v-v')$.

12. Any number of rotatory forces being given, by decomposing each into three, the axes of which are confined within the three planes of coordinates, and by recomposing

---

* The decomposition and recomposition of rotatory forces acting upon a given plane, as well as of ordinary forces acting upon a given point, is immediately derived from the principle of the coexistence of infinitesimal movements, which may be replaced by the causes producing them, *i. e.* by forces.

again the forces having their axes in the same plane, the following values are obtained for the intensities and the moments of the three resulting new forces:

$$\Sigma\mathfrak{X},\quad \frac{\Sigma\mathfrak{X}}{\pi},$$

$$\Sigma\mathfrak{Y},\quad \frac{\Sigma\mathfrak{Y}}{\varkappa},$$

$$\Sigma\mathfrak{Z},\quad \frac{\Sigma\mathfrak{Z}}{\varrho},$$

in putting, for brevity,

$$\Sigma\,\frac{\mathfrak{X}}{p}=\frac{\Sigma\mathfrak{X}}{\pi},$$

$$\Sigma\,\frac{\mathfrak{Y}}{q}=\frac{\Sigma\mathfrak{Y}}{\varkappa},$$

$$\Sigma\,\frac{\mathfrak{Z}}{r}=\frac{\Sigma\mathfrak{Z}}{\varrho}.$$

In the general case the three resulting rotatory forces constitute, if compounded, a (rotatory) dyname. In denoting the intensity of its force and moment by Π and P, we have

$$(\Sigma\mathfrak{X})^2+(\Sigma\mathfrak{Y})^2+(\Sigma\mathfrak{Z})^2=\Pi^2,$$

$$\left(\Sigma\,\frac{\mathfrak{X}}{p}\right)^2+\left(\Sigma\,\frac{\mathfrak{Y}}{q}\right)^2+\left(\Sigma\,\frac{\mathfrak{Z}}{r}\right)^2=\mathrm{P}^2,$$

while the ratios

$$\Sigma\mathfrak{X}:\Sigma\mathfrak{Y}:\Sigma\mathfrak{Z}=\cos l:\cos\mu:\cos r,$$

$$\Sigma\,\frac{\mathfrak{X}}{p}:\Sigma\,\frac{\mathfrak{Y}}{q}:\Sigma\,\frac{\mathfrak{Z}}{r}=\cos a:\cos b:\cos c$$

give the angles l, m, n and a, b, c, made by the axes of rotation and the axis of the moments with OX, OY, OZ.

If

$$\cos l\cos a+\cos m\cos b+\cos n\cos c=0,$$

the resulting dyname degenerates into a mere rotatory force of given intensity and position in space.

In the case of equilibrium,

$$\Sigma\mathfrak{X}=0,\quad \Sigma\mathfrak{Y}=0,\quad \Sigma\mathfrak{Z}=0,$$

$$\Sigma\,\frac{\mathfrak{X}}{p}=0,\quad \Sigma\,\frac{\mathfrak{Y}}{q}=0,\quad \Sigma\,\frac{\mathfrak{Z}}{r}=0.$$

If only the three last of these six equations equivalent to the following ones,

$$\frac{\Sigma\mathfrak{X}}{\pi}=0,\quad \frac{\Sigma\mathfrak{Y}}{\varkappa}=0,\quad \frac{\Sigma\mathfrak{Z}}{\varrho}=0,$$

are satisfied, π, $\varkappa$, ϱ become infinite; accordingly the three axes of the rotatory forces (10) are, within three planes of coordinates, at an infinite distance, and consequently the corresponding rotatory movements are replaced by translatory ones, parallel to the planes of coordinates. The three movements thus obtained give a resulting movement of the same kind.

If only the first three of the six equations are satisfied, π, $\varkappa$, ϱ becoming equal to zero, the resulting axis of rotation passes through the origin.

13. After this digression, by which a full analogy between ordinary forces and forces producing rotation is stated, we may proceed by giving most succinct indications only.

With regard to rotations and forces producing them, we have to distinguish two different kinds of complexes corresponding to their different systems of coordinates. We shall first, in making use of the coordinates

$$t-t',\quad u-u',\quad v-v',\quad uv'-u'v,\quad vt'-v't,\quad tu'-t'u,$$

consider a complex of rotations, the coordinates of which satisfy the equation

$$\mathrm{D}(t-t')+\mathrm{E}(u-u')+\mathrm{F}(v-v')+\mathrm{A}(uv'-u'v)+\mathrm{B}(vt'-v't)+\mathrm{C}(tu'-t'u)=1,$$

which, for brevity, may be written thus,

$$\Theta=\mathrm{H}-1=0.$$

In regarding t', u', v' as constant, any fixed plane traversing space is the plane acted upon by the rotatory forces, and therefore containing the axes of rotation. The coordinates of the second planes (t, u, v), by means of which the corresponding rotations of the complex are determined, remaining variable, the same equation representing the complex now represents a *point*, where all second planes meet. The equation of this point may be written thus,

$$\begin{aligned}&(\mathrm{D}+\mathrm{C}u'-\mathrm{B}v')t\\&(\mathrm{E}-\mathrm{C}t'+\mathrm{A}v')u\\&(\mathrm{F}+\mathrm{B}t'-\mathrm{A}u')v\\&=\mathrm{D}t'+\mathrm{E}u'+\mathrm{F}v-1;\end{aligned}$$

whence the following coordinates of the point are obtained,

$$x=\frac{\mathrm{D}+\mathrm{C}u'-\mathrm{B}v'}{\mathrm{D}t'+\mathrm{E}u'+\mathrm{F}v'-1},$$

$$y=\frac{\mathrm{E}-\mathrm{C}t'+\mathrm{A}v'}{\mathrm{D}t'+\mathrm{E}u'+\mathrm{F}v'-1},$$

$$z=\frac{\mathrm{F}+\mathrm{B}t'-\mathrm{A}u'}{\mathrm{D}t'+\mathrm{E}u'+\mathrm{F}v'-1}.$$

We shall call this point the point conjugate to the plane (t', u', v').

Any plane traversing space may be regarded as acted upon by the forces of the complex, each right line it confines, as an axis. The rotation corresponding to each axis is determined by a second plane, traced through the conjugate point and the axis.

The intensity P of each rotatory force is thus immediately given. P becomes infinite for all rotations the second planes of which pass through the origin. In considering exclusively rotations of this description, the six coordinates of which are likewise infinite, the equation of the complex becomes

$$H=0.$$

Being now homogeneous, it represents a linear complex of axes or right lines, *identical* with the complex represented in Part I. by the equations

$$\Omega=0, \text{ or } \Phi=0.$$

It would be beyond the limits of this paper to develope here the theory of linear complexes of rotations. Let me observe only that, in taking for OZ the axis of the complex H, which may be regarded likewise as the axis of the complex of rotations Θ, the general equation of the complex assumes the following form,

$$v-v'+\varkappa(tu'-t'u)=\varkappa\varkappa',$$

in denoting by $\varkappa$ and $\varkappa'$ two constants, and may in retaining the former notation be written thus,

$$P\left(\cos\nu+\varkappa.\frac{\cos\gamma}{\delta}\right)=\varkappa\varkappa'.$$

There are amongst the rotations of the complex such transformed into translations. They will be determined in putting $\delta=\infty$, whence

$$P\cos\nu=\varkappa\varkappa'.$$

14. The congruent rotations of any *two* complexes,

$$\Theta=0, \qquad \Theta'=0,$$

constitute a *congruency of rotations.* Any plane being given, there is in each complex a point conjugate to the plane; the line joining both points may be called *conjugate in the congruency to the given plane.* Each plane passing through the conjugate line intersects the given plane along an axis of rotation. Therefore all axes within the plane *meet in the same point*, where it is intersected by its conjugate line. Among the axes there is one confined in the plane passing through the origin; in the corresponding rotation P becomes infinite. Again, there is one rotation transformed into a displacement parallel to the given plane.

In accordance with these results, the equation

$$\Theta-\Theta'=0,$$

derived from the preceding ones by eliminating their constant term, represents a *linear complex of axes.*

15. The congruent rotations of *three* complexes,

$$\Theta=0, \qquad \Theta'=0, \qquad \Theta''=0,$$

constitute a *double congruency of rotations.* Any plane traversing space being given, there is another plane passing through the three points conjugate in the three complexes to the given one. This plane may be called *conjugate in the double congruency to the given plane.* There is within the given plane *one single axis of rotation* coinciding with the intersection of both planes, that given, and its conjugate one.

The axes of rotation belonging to a double congruency constitute a linear congruency of right lines, represented by

$$\Phi-\Phi'=0, \quad \Theta-\Theta'=0,$$

and consequently meet two fixed lines.

16. The axes of the congruent rotations of *four* complexes are directed along the generatrices of a hyperboloid. Hence we conclude that all axes of rotation are confined within the tangent planes of the hyperboloid. Such a plane being given, its four conjugate points in the four complexes are within the same conjugate plane, intersecting the given tangent plane along the axis of rotation which it contains. There is within the given tangent plane a line of the other generation of the hyperboloid. When the tangent plane revolves round this line, the corresponding axis of rotation, in revolving simultaneously, in all its positions intersects the line in a point which describes it, while the axis of rotation describes the hyperboloid.

17. There are two rotations coincident in five complexes.

18. The *second* kind of complexes of rotations is represented by the equation

$$\mathrm{D}\mathfrak{X}+\mathrm{E}\mathfrak{Y}+\mathrm{F}\mathfrak{Z}+\mathrm{A}\mathfrak{L}+\mathrm{B}\mathfrak{M}+\mathrm{C}\mathfrak{N}=1,$$

in regarding X, Y, Z, L, M, N, involving the condition

$$\mathfrak{L}\mathfrak{X}+\mathfrak{M}\mathfrak{Y}+\mathfrak{N}\mathfrak{Z}=0,$$

as variable coordinates. All discussions regarding the new complexes are analogous to former ones.

19. In not admitting the last equation of condition, the complex of rotations of the second kind is replaced by a complex of (rotatory) dynames.

III.

From the notions developed in Parts I. and II. we immediately obtain two general theorems, constituting the base of statics. In a similar way, as D'ALEMBERT'S principle is derived from the "principe des vitesses virtuelles," both theorems may be transformed into fundamental theorems of mechanics.

Any forces acting upon a rigid body may be resolved into forces producing translation and forces producing rotation. In the case of equilibrium, neither a translatory nor a rotatory movement takes place, *i. e.* the resulting forces of both kinds become equal to zero.

In denoting the ordinary forces by

$$(x', y', z', \quad x, y, z),$$

the rotatory forces by

$$(t', u', v', \quad t, u, v),$$

the equations of equilibrium are

$$\Sigma(x-x')=0, \quad \Sigma(y-y')=0, \quad \Sigma(z-z')=0,$$
$$\Sigma(t-t')=0, \quad \Sigma(u-u')=0, \quad \Sigma(v-v')=0.$$

In putting, n being the number of forces,

$$\begin{array}{lll} \Sigma x' \equiv n\xi', & \Sigma y' \equiv n\eta', & \Sigma z' \equiv n\zeta', \\ \Sigma x \equiv n\xi, & \Sigma y \equiv n\eta, & \Sigma z \equiv n\zeta, \\ \Sigma t' \equiv n\vartheta', & \Sigma u' \equiv n\varrho', & \Sigma v' \equiv n\sigma', \\ \Sigma t \equiv n\vartheta, & \Sigma u \equiv n\varrho, & \Sigma v \equiv n\sigma, \end{array}$$

(ξ', η', ζ') and (ξ, η, ζ) are the *centres of gravity* of the two systems of points (x', y', z') and (x, y, z); likewise $(\vartheta', \varrho', \sigma')$ and $(\vartheta, \varrho, \sigma)$ the *central planes* (II. No. 9) of the two systems of planes (t', u', v') and (t, u, v). Accordingly the equations of equilibrium become

$$\begin{array}{lll} \xi=\xi', & \eta=\eta', & \zeta=\zeta', \\ \vartheta=\vartheta', & \varrho=\varrho', & \sigma=\sigma'. \end{array}$$

We commonly represent ordinary forces by means of right lines, analytically by means of the coordinates of their extremities, *i. e.*, by the coordinates of the points acted upon (x', y', z') and the coordinates of second points (x, y, z). In an analogous way rotatory forces are represented by axes and couples of planes passing through them; analytically by the coordinates of planes acted upon (t', u', v'), and the coordinates of second planes (t, u, v). Accordingly in the case of equilibrium—

I. *The centre of gravity of the points acted upon by the forces coincides with the centre of gravity of the second extremities of the right lines by which the forces are represented.*

II. *The central plane of the planes acted upon by the rotatory forces coincides with the central plane of the second planes, by which these forces are determined.*

If we introduce the notion of *masses* both theorems hold good, only the definition of both kinds of forces and therefore their unity is changed. The points acted upon become centres of gravity, corresponding to masses; the planes acted upon central planes, corresponding to moments of inertia.

If equilibrium does not exist, there is in the general case one resulting ordinary force, determined by the two centres of gravity, and one resulting rotatory force, determined by the two central planes. The intensities of the two forces are

$$n\sqrt{(\xi-\xi')^2+(\eta-\eta')^2+(\zeta-\zeta')^2},$$
$$n\sqrt{(\vartheta-\vartheta')^2+(\varrho-\varrho')^2+(\sigma-\sigma')^2}.$$

These forces decomposed into three are known, and therefore the direction of the axes, both of translation and rotation. We get easily the six differential equations of the movement produced.

I shall think it suitable further to develope the principles here merely indicated. A Treatise on Mechanics, reconstructed on them, will assume quite a new aspect.

XVII. *Further Observations on the Spectra of some of the Nebulæ, with a Mode of determining the Brightness of these Bodies.* By William Huggins, *F.R.S.*

Received January 30,—Read February 15, 1866.

§ I. *Introduction.*

In my former papers, "On the Spectra of some of the Nebulæ" *, and "On the Spectrum of the Great Nebula in Orion" †, I described the results of a prismatic examination of the light of some of the objects in the heavens which have been classed together under the common denomination of Nebulæ. The present paper contains the results of the application of the same method of research, with the same apparatus, to the light of others of the same class of bodies. To these observations with the prism are appended the results of an attempt to determine the intrinsic intensity of the light emitted by some of the nebulæ which give a spectrum indicating gaseity.

On account of the great faintness of the light of most of the objects described in this paper, I have not found it possible to determine more than the general characters of the spectra which they form in the instrument. The present observations confirm the results which I have already presented to the Royal Society, namely, that with my instrument clusters and nebulæ give either a spectrum which is apparently continuous, or a spectrum consisting of one, two, or three bright lines.

The description "continuous spectrum" in this paper and in my former papers must not be understood to mean more than that when the slit was made as narrow as the feeble light of the object permitted, the spectrum was not resolved into bright lines. Whether the continuous spectrum was in any case interrupted by dark lines in a manner similar to the spectra of the sun and fixed stars, I was not able to ascertain; for when the feeble light of a nebula is dispersed by the prism into a spectrum consisting of light of all refrangibilities, the spectrum is extremely faint and difficult of examination. Before the slit is made sufficiently narrow for the detection of dark or bright lines, the spectrum becomes, in the case of nearly all the objects examined, too faint to be visible. When, however, a nebula is observed the light of which is monochromatic, or nearly so, the one, two, or three bright lines in which the light remains concentrated can usually be seen when the slit is made narrow. Some of these nebulæ have been examined with a slit not exceeding $\frac{1}{300}$ of an inch in width.

[A conclusion of some importance to our interpretation of the phenomena of these bodies, and especially of value in reference to the theoretical views we may form of the relation of the gaseous nebulæ to the other nebulæ and clusters, presents itself in connexion with these observations. The intensity of the brightest line of the gaseous nebulæ is in most cases greater than the intensity of the light of the *same refrangibility* of those nebulæ and clusters which furnish a spectrum which is apparently continuous. The superior intensity of the light may indicate a more intense heat. It may be therefore that of all the objects usually classed under the denomination of nebulæ and clusters, those which give a gaseous spectrum are, as a class, to be regarded as the *hottest.*—June 1866.]

---

* Philosophical Transactions, 1864, p. 437.

† Proceedings of the Royal Society, vol. xiv. p. 39.

The continuous spectra of some of the nebulæ and clusters are irregularly bright in some parts of the spectrum; but when the width of the slit was reduced, the bright portions did not appear to become more defined, as would be the case with a spectrum containing bright lines*. This irregularity of brightness may perhaps be due in some cases to the probable mode of formation of these continuous spectra. In the case, at least, of the clusters which the telescope resolves into stellar points, the spectrum must be composed of the blending together of the spectra of the constituent bright points. Now it is not improbable that these component spectra, like the spectra of the stars, differ from each other in the relative brightness of their different parts.

The positions in the spectrum of the bright lines of the gaseous nebulæ described in my former paper were determined by a simultaneous comparison in the instrument of these lines with the bright lines of nitrogen, hydrogen, and barium. The bright lines of the gaseous nebulæ referred to in this paper were not compared directly with any terrestrial spectra, partly because of the great faintness of most of these objects, and partly because the former comparisons were found to be injuriously fatiguing to the eye.

The value of this application of spectrum analysis appears to me to consist chiefly in the assistance which this method of observation may afford us in ascertaining the true nature of the nebulæ, and the relation which they sustain to the other orders of the heavenly bodies. I have therefore added to my prismatic observations such of the

* The peculiar appearance of the continuous spectra of some of the nebulæ and clusters has suggested to me, from my first examination of them, that possibly the luminous points into which the telescope resolves some of these objects may not be of the same nature as the true stars. My observations of the great nebula in Andromeda and of its small but bright companion in August 1864, were recorded thus:—"The spectrum appears to end abruptly in the orange; and throughout its length is not uniform, but is evidently crossed either by lines of absorption or by bright lines"[1]. [The same characters have since been found in several of the brighter nebulæ and clusters. It is possible to explain the absence of the less refrangible rays, which are wanting in these spectra, by supposing them to have been intercepted by absorbent vapours. The apparently *complete* want of light in this part of the spectrum, and the unequal, mottled appearance of the brighter parts of the spectrum, suggest rather that the light may have emanated from a gaseous source, and that the spectrum consists of numerous *bright* lines. The faintness of these spectra has prevented me from using a slit sufficiently narrow for the determination of their true nature. Some quite recent observations, which are not yet complete, appear to support the view that the bright points of some clusters may possess a physical constitution which is not analogous to that of the sun, and the brighter of the separate stars.—June 1866.]

---

[1] Philosophical Transactions, 1864, p. 442.

results of former telescopic observation as, in my opinion, would be of assistance to an understanding of the proper significance of the new information furnished by the prism.

[Although the detection in a nebula by the telescope of closely associated points of light can no longer be regarded as a trustworthy indication that the object consists of true stars, yet it is of importance to ascertain how far the classification of the nebulæ by the prism corresponds with the telescopic indications of their resolvability. I have Lord ROSSE's permission to state that the matter of the Great Nebula in Orion, which the prism shows to be gaseous, has not been resolved by his telescope. In some parts of the nebula he observed a large number of exceedingly minute *red* stars. These red stars, however, though apparently connected with the irresolvable blue material of the nebula, yet seem to be distinct from it. The light of these stars is doubtless too feeble to furnish a visible spectrum.

Lord OXMANTOWN has examined all the observations made at Parsonstown of those nebulæ which I have subjected to prismatic examination. My list contained 41 nebulæ which give a continuous spectrum, and 19 gaseous nebulæ.

Lord OXMANTOWN finds that these nebulæ may be arranged thus:—

	Continuous spectrum.	Gaseous spectrum.
Clusters	10	0
Resolved, or resolved?	5	0
Resolvable, or resolvable? . . .	10	6
{Blue, or green, no resolvability . .	0	4
No resolvability seen	6	5
Total observed . .	31	15
Not observed . . .	10	4
	41	19—June 1866.]

The numbers and descriptions of the nebulæ, and their places for the epoch 1860.0, included within brackets, are taken from Sir JOHN F. W. HERSCHEL'S "General Catalogue of Nebulæ and Clusters of Stars"*.

§ II. *Observations of Nebulæ the Spectra of which indicate gaseity.*

[No. 2102. 3248 h. 27 H. IV. R.A. $10^h\,18^m\,2^s{\cdot}2$. N.P.D. 107° 55′ 50″. A planetary nebula. Very bright; little extended; position of longer dimension 135°; diameter $=32''\pm$; blue.]

This nebula was observed on April 25, 1865, with a silvered glass reflector. The spectrum consisted of one bright line about midway between *b* and F of the solar spectrum, and probably corresponding in position to the brightest of the lines of nitrogen.

In consequence of the imperfect adjustment, at this time, of the reflector, I was unable to ascertain satisfactorily whether any other fainter lines were also present in the spectrum.

---

* Philosophical Transactions, 1864, pp. 1–137.

Sir John Herschel describes its appearance as "somewhat hazy, with a slight nebulous atmosphere"[*].

D'Arrest's measures of the diameter are—January 13, 1856, $=25''$, and March 11, 1856, $=27''$[†].

[On March 14, 1866, I examined this nebula with my refractor of 8 inches aperture. Powers of 600 and 920 diameters showed that the nebula is annular. It appears to consist of an oval ring of brighter matter surrounded by a broad margin of faint nebulosity. The area enclosed by the ring, like that of the annular nebula in Lyra, is filled with faintly luminous matter. The faint nebulosity surrounding the ring appears circular, or nearly so, suggesting that the ring, seen obliquely from our system, exists within a globular mass of faint nebulous material.

When the spectroscope was applied, in addition to the bright line seen in 1865, the two other bright lines which are present in many nebulæ, were also observed. When the slit was made sufficiently narrow for these bright lines to appear defined, no trace of a continuous spectrum was detected. With a wide slit, however, I *suspected* a faint and broad continuous spectrum.—June 1866.]

[No. 4234. 1970 h. 5 Σ. R.A. $16^h\ 38^m\ 36^s$. N.P.D. 65° 56′ 10″. A planetary nebula; very bright; very small; disk and border.]

I observed this nebula, and all the objects which follow in this paper, with my refractor of 8 inches aperture.

On this nebula powers up to 1000 diameters were employed. With low powers this object appeared small, round, intensely bright, and decidedly blue in colour. Higher powers showed a uniform disk surrounded with a faint nebulous halo.

The prism resolves the light of this nebula into three bright lines, occupying the same positions in the spectrum as the bright lines of nebula No. 4373[‡]. The two brightest lines are bright, and differ not very greatly in intensity; the less refrangible of the lines is the brighter. The most refrangible of the three lines is much fainter than the others.

A very faint continuous spectrum was seen by glimpses.

Lord Rosse describes this nebula:—"Intense blue centre fading off to some distance all around. I found once or twice there were projections. (N.B. The existence of these not satisfactorily proved"[§].)

Sir John Herschel gives its diameter $=8''$[‖].

D'Arrest's measures of its diameter are—1856, March 12, $=6''$, June 1, $=8''$[¶].

---

[*] Results of Astronomical Observations at the Cape of Good Hope, p. 94, and pl. 6, fig. 5.

[†] Resultate aus Beobachtungen der Nebelflecken und Sternhaufen, p. 326.

[‡] Philosophical Transactions, 1864, p. 438.

[§] Ibid. 1861, p. 732.

[‖] Ibid. 1833, p. 458.

[¶] Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

[No. 4403. 2008 h. 17 M. R.A. $18^h\,12^m\,33^s$. N.P.D. 106° 13′ 36″. Remarkable object. Bright; extremely large; extremely irregular figure; 2-hooked.]

Sir JOHN HERSCHEL observes of this nebula, "A most curious object, not unlike the nebula of Orion (as it used to be figured like a Greek capital omega, Ω). There is in it a resolvable portion * or knot distinctly separated from and insulated in the rest, as if it had absorbed the nebula near it. Its form is like the Greek Ω, with the left (or following) base-line turned upwards. The curved or horseshoe part is very faint, and has many stars in it; the preceding base-line hardly visible. Its light is not equable, but blotty "†.

Lord OXMANTOWN informs me that in the observations of this nebula at Birr Castle there is no mention of resolvability; and that "the central part to the right of star α consists of bunches or patches of bright nebulosity, with fainter nebulosity intervening."

The spectrum of this nebula indicates that it possesses a gaseous constitution. One bright line only was seen, occupying in the spectrum apparently the same position as the brightest of the lines of nitrogen. When the slit was made as narrow as the intensity of the light would permit, this bright line was not so well defined as the corresponding line in some of the other nebulæ under similar conditions of the slit, but remained nebulous at the edges.

When the brightest portion of the nebula containing the nucleus or "bright knot" was brought upon the slit, in addition to the bright line a faint narrow continuous spectrum was seen.

The bright knot appeared in my telescope smaller and more condensed than it is represented in the drawings of Sir JOHN HERSCHEL.

[No. 4572. 2075 h. 16 H. IV. R.A. $20^h\,16^m\,7^s{\cdot}9$. N.P.D. 70° 20′ 19″·3. A planetary nebula; bright; pretty small; round; four stars near.]

"Rather hazy at the edges, but not materially brighter in the middle, but no hollow. It has four stars near it like satellites. Diameter in R.A. 30″±. Its light is a little mottled, but it is well defined "‡.

Lord ROSSE remarks, "This planetary nebula is a beautiful little spiral. Star or bright nucleus north following the middle "§.

"Dieser Nebel hat sich seit 30 Jahren bestimmt nicht nachweisbar bewegt. Klein aber ziemlich hell, 25″ diam., rund und durchaus gleichförmig hell; erscheint in der That wie eine Nebelscheibe."—D'ARREST ‖.

---

* "Mr. MASON declares the upper and larger knot to be irresolvable by his telescope (a reflector of 12 inches aperture and 14 feet focal length). In this particular my observations of 1835 and 1837 so far agree, that its resolvability is not mentioned in words or indicated in the diagrams made on those occasions."—Sir JOHN HERSCHEL, 'Results of Astronomical Observations at the Cape of Good Hope,' p. 7, and pl. 2, fig. 1.

† Philosophical Transactions, 1833, p. 461, and Plate XII. fig. 35.

‡ Philosophical Transactions, 1833, p. 467, and Plate XIII. fig. 47.

§ Ibid. 1861, p. 733, and Plate XXVII. fig. 34.

‖ Beobachtungen der Nebelflecken und Sternhaufen, p. 349.

"Durchmesser gemessen $=27''$."—SCHULTZ[*].

The spectrum of this nebula consisted of one bright nebulous line of the same refrangibility as the brightest of the lines of nitrogen. No other lines were *certainly* seen.

The three brighter of the enclosing stars gave the usual stellar continuous spectrum.

Sir JOHN HERSCHEL remarks of these stars near the nebula, "The point to which I would draw attention is the frequent and close proximity to these objects (the planetary nebulæ) of minute stars, which suggest the idea of accompanying satellites"[†].

D'ARREST, referring to these small stars, says (in 1856), "Von den Satelliten der planetarischen Nebelflecken die widergesehenen standen noch unverrück in den von Sir J. HERSCHEL so sorgfältig bestimmten Stellungen, oder können sich im Laufe der letzten Vierteljahrhunderts nur sehr kleine Grössen daraus entfernt haben.". . . . "Von etwa drittehalb Hundert Nebeln lässt es sich sehr wahrsheinlich machen, dass eigene jahrliche Bewegungen im Betrage von mehr als einer Bogensekunde nicht vorhanden sind. Streng beweisen endlich lässt sich vollständige Unmerklichkeit der Eigenbewegung während der letzten 60 Jahre bei einigen unter den planetarischen Nebelflecken"[‡].

[No. 4499. 2043 h. 38 H. VI. R.A. $19^{h}\ 24^{m}\ 53^{s}$. N.P.D. $81°\ 3'\ 37''\cdot8$. Considerably bright; small; irregularly round; well resolved.]

"A very small roundish cluster, $40''$ diam., of very small stars, one brighter than the rest. It is like a nebula well resolved, and is a curious object. . . . . . Doubtful if a resolved cluster, or a nebula of the first class."—Sir JOHN HERSCHEL[§].

"Four stars in nebula, and two more on preceding edge."—Lord ROSSE[‖].

"Suspect more smaller stars"[¶].—Lord OXMANTOWN.

---

[*] Astron. Nachrichten, No. 1541.

[†] Philosophical Transactions, 1833, p. 500.

[‡] Beobachtungen der Nebelflecken und Sternhaufen, p. 308.

Some observers describe indications of the occurrence of continual and very rapid variations in the light of some of the gaseous nebulæ. It must not be forgotten, however, that in the nebulæ only phenomena of enormous magnitude could be visible to us. Besides this consideration, in the constantly varying state of our atmosphere, and in the variation in the power of the eye to appreciate minute differences of relative brightness when the conditions of illumination of the object are different, we have probably a sufficient explanation of these phenomena.

M. O. STRUVE (in 1856) says, ". . . the general impression that I have derived from the observations of this year, has been that the central part of the nebula of Orion is in a state of continual change with regard to the brightness in different parts of it. Even with the best definition, its appearances were to me on no evening entirely agreeing with those on the next or any other night."—Monthly Notices Royal Astron. Soc. vol. xvii. p. 230.

Dr. A. SCHULTZ (in 1865) observes of No. 4234, 1970 h., "Der Nebel flammt nicht in gewöhnlicher Weise, zeigt aber eine anaufhörlich gleichmässige Dilatation und Contraction." And also of No. 4572, 2075 h., "Momentan werschwindet die Nebulosität ganz (?) und der Nebel zeigt sich wie ein sehr reicher gedrängter Sternhaufen."—Astronom. Nachrichten, No. 1541.

[§] Philosophical Transactions, 1833, p. 464.

[‖] Ibid. 1861, p. 732.

[¶] This observation, and those of other nebulæ to which the name of Lord OXMANTOWN is attached, have been kindly extracted for me from the observations made at Birr Castle.

The spectrum of this nebula, or at least of some parts of it, is almost certainly of the order which indicates that the source of the light is gaseous matter. I believe that the spectrum consists of one bright line. The object, however, is very faint, and the determination of its spectrum with my instrument very difficult. I examined the light of this nebula several times, with eyepieces of different powers applied to the small telescope of the spectroscope, but in all the observations I was confirmed in the opinion that the greater part at least of the light is monochromatic.

Probably there is, in addition to the bright line or lines, a faint continuous spectrum, which may belong to the stars which are visible within the nebula.

[No. 4827. 2178 h. 705 H. II. R.A. $22^h\ 35^m\ 6^s{\cdot}6$. N.P.D. 29° 27′ 5″·4. Bright; small; round; gradually very little brighter in the middle; easily resolvable.]

"Planetary?"—Lord Rosse *.

"Three stars preceding. Resolvable?"—Lord Oxmantown.

One bright line only was distinctly seen in the spectroscope.

On account of the faintness of the object, I am unable to say whether any other fainter lines are also present, or a faint continuous spectrum.

[No. 4627. 2099 h. 192 H. I. R.A. $20^h\ 56^m\ 17^s{\cdot}5$. N.P.D. 35° 59′ 39″·6. Considerably bright; large; barely resolvable; two stars attached.]

"Has an appearance of two nuclei or points of greatest condensation; it touches a fine double star."—Sir John Herschel †.

"The nebula has three knots in it."—Lord Rosse ‡.

"No mention of resolvability."—Lord Oxmantown.

The different knots of this nebula give a spectrum indicating gaseity, though in the examination of some parts of the nebula I suspected the presence of a faint continuous spectrum as well. The continuous spectrum may possibly belong to the small stars which are represented in Lord Rosse's drawing of this object.

One bright line only was distinctly seen, of apparently the same refrangibility as the brightest of the nitrogen line. This bright line appeared by glimpses to be double. Possibly this appearance was due to the presence near it of a second line. The faintness of the light did not permit the slit to be made sufficiently narrow for the determination of this point.

[[No. 385. 76 M. R.A. $1^h\ 33^m\ 28^s{\cdot}5$. N.P.D. 39° 8′ 52″·4. Very bright; preceding of double nebula.

No. 386. 193 H. 1. R.A. $1^h\ 33^m\ 37^s{\cdot}5$. N.P.D. 39° 7′ 27″·4. Very bright; following of double nebula.]

Both parts of this double nebula give a gaseous spectrum. The brightest only of the three lines usually present was *certainly* seen. The second line is probably also present.

I suspected a faint continuous spectrum at the preceding edge of No. 386.

---

* Philosophical Transactions, 1861, p. 735.

† Ibid. 1833, p. 469.

‡ Ibid. 1861, p. 734, and Plate XXX. fig. 37.

[No. 2343. 838 h. 97 M. R.A. $11^h\ 6^m\ 34^s{\cdot}8$. N.P.D. 34° 13′ 38″·2. Planetary; very bright; very large; round; very gradually, very suddenly brighter in the middle.]

"A large uniform nebulous disk, diameter $19^s{\cdot}0$ in R.A. Quite round, very bright, not sharply defined, but yet very suddenly fading away to darkness."—Sir JOHN HERSCHEL*.

"Two stars considerably apart in the central region, dark penumbra round each spiral arrangement, with stars as apparent centres of attraction. Stars sparkling in it; resolvable."—Lord ROSSE†.

"Two stars were easily seen in this nebula formerly; since 1850 only one has been seen. Not observed since April 1864."—Lord OXMANTOWN.

The spectrum consists of the two brighter of the lines usually present. A continuous spectrum is doubtful. Once or twice a very faint continuous spectrum was suspected. —June 1866.]

§ III. *Observations of Nebulæ the spectra of which are apparently continuous.*

[No. 105. 44 h. 18 H. V. R.A. $0^h\ 32^m\ 45^s{\cdot}4$. N.P.D. 49° 4′ 49″·8. Very bright; very gradually very much brighter in the middle.]

"Very large, much extended. Sharp nucleus, round which for some distance the nebula is bright, and then suddenly decreases; spirality suspected."—Lord ROSSE‡.

"Small stars seen on one occasion in the nucleus."—Lord OXMANTOWN.

Spectrum continuous.

[No. 307. 117 h. 151 H. I. R.A. $1^h\ 17^m\ 26^s{\cdot}8$. N.P.D. 81° 11′ 50″·3. Very bright; much brighter in the middle.]

Spectrum continuous.

[No. 575. 242 h. 156 H. I. R.A. $2^h\ 31^m\ 38^s$. N.P.D. 51° 32′ 45″·9. Very bright; very large; very much extended; very much brighter in the middle§.]

"Six stars seen in it distinctly, others suspected about centre. Nucleus suspected to be composed of stars."—Lord OXMANTOWN.

Centre of the nebula very bright. The spectrum of this bright central part alone was satisfactorily seen. This spectrum is continuous.

[No. 1949. 649 h. 81 M. R.A. $9^h\ 43^m\ 48^s{\cdot}9$. N.P.D. 20° 16′ 10″. Extremely bright; extremely large; gradually, suddenly very much brighter in the middle.]

Spectrum continuous; the red end of the spectrum wanting or very faint.

[No. 1950. 82 M. R.A. $9^h\ 43^m\ 52^s{\cdot}3$. N.P.D. 19° 34′ 16″·3. Very bright; very large; very much extended, "a beautiful ray."]

Spectrum continuous. The absence or great faintness of the red portion of the spectrum more marked than in the spectrum of No. 1949.

[No. 3572. 1622 h. 51 M. R.A. $13^h\ 23^m\ 55^s{\cdot}4$. N.P.D. 42° 5′ 4″. Remarkable; nucleus and ring (*h*); spiral (R).]

---

* Philosophical Transactions, 1833, p. 402, also Plate X. fig. 32.

† Ibid. 1850, p. 513, and Plate XXXVII. fig. 2.

‡ Ibid. 1861, p. 709.

§ See also drawing by Lord ROSSE, Philosophical Transactions, 1861, Plate XXX. fig. 5.

"The outer nucleus unquestionably spiral with a twist to the left."—Lord Rosse[*].

"Both nuclei resolved; brighter parts of spiral branches suspected to be resolved. Stars innumerable, though I feel satisfied that it is not a cluster."—Lord Oxmantown.

"Nos observations n'accusent aucun changement dans la position relative des deux têtes dans l'intervalle de 13 ans."—O. Struve[†].

Each of the bright centres brought successively upon the slit. Spectrum continuous. A suspicion that some parts of the spectrum were abnormally bright relatively to the other parts.

[No. 2841. 1175 h. 43 H. V. R.A. $12^h\,12^m\,1^s{\cdot}7$. N.P.D. 41° 55′ 40″·6. Very bright; very large; suddenly brighter in the middle; bright nucleus.]

"A very large bright extended nebula; much mottled."—Lord Rosse[‡].

Spectrum continuous. A suspicion of unusual brightness about the middle part of the spectrum.

[No. 3474. 1570 h. 63 M. R.A. $13^h\,9^m\,31^s{\cdot}9$. N.P.D. 47° 13′ 45″·3. Very bright; large; very suddenly much brighter in the middle; bright nucleus.]

"Spiral? darkness south following nucleus."—Lord Rosse[§].

Spectrum continuous.

[No. 3636. 1663 h. 3 M. R.A. $13^h\,35^m\,40^s$. N.P.D. 60° 55′ 6″. Cluster; extremely bright.]

"Ein leicht auflöslicher Hauf zahllosen Sterne, in der Mitte zu einem einzigen Lichte von grosser helligkeit zusammenlaufend."—D'Arrest[||].

Spectrum continuous.

[No. 4058. 1909 h. 215 H. I. R.A. $15^h\,2^m\,36^s{\cdot}3$. N.P.D. 33° 41′ 39″·4. Very bright; considerably large; gradually brighter in the middle.]

"None of the component stars to be seen. Resolvability strongest near nucleus."—Lord Oxmantown.

Spectrum continuous.

[No. 4159. 1945 h. R.A. $15^h\,58^m\,49^s{\cdot}9$. N.P.D. 81° 31′ 23″·2. Star 7th mag. in photosphere.]

No unusual appearance was detected in the continuous spectrum of the star.

[No. 4230. 1968 h. 13 M. R.A. $16^h\,36^m\,41^s{\cdot}2$. N.P.D. 53° 16′ 19″·4. Cluster; extremely bright.]

Spectrum of the central blaze continuous. Spectrum ends abruptly in the orange. The light of the brighter part is not uniform; probably it is crossed either by bright lines or by lines of absorption.

[No. 4238. 1971 h. 12 M. R.A. $16^h\,39^m\,58^s{\cdot}1$. N.P.D. 91° 41′ 47″·4. Cluster; very bright.]

"Hairy branches with slightly spiral arrangement."—Lord Oxmantown.

---

[*] Philosophical Transactions, 1861, p. 728; also ibid. 1850, Plate XXXV. fig. 1.

[†] Bulletin de l'Académie Imp. des Sciences de St. Pétersbourg, tom. vii. p. 361.

[‡] Philosophical Transactions, 1861, p. 725.

[§] Ibid. p. 729.

[||] Beobachtungen der Nebelflecken und Sternhaufen, p. 338.

Spectrum continuous.

[No. 4244. 50 H. IV. R.A. $16^{h}\ 43^{m}\ 6^{s}\cdot 4$. N.P.D. $42^{\circ}\ 8'\ 38''\cdot 8$. Very bright; large. round; disk + faint, barely resolvable, border.]

"Eine kleine Nebelsheibe, hell=✱9 Gr., umgeben von einer merklich schwächern Nebelhülle; kreisrund 1′ diam. Ruhiges Licht, bläulich."—D'ARREST[*].

Spectrum continuous. No appearance of bright lines when the slit was made narrow.

[No. 4256. 10 M. R.A. $16^{h}\ 49^{m}\ 47^{s}\cdot 6$. N.P.D. $93^{\circ}\ 52'\ 6''\cdot 8$. Cluster; bright; well resolved.]

"The most important stars take a spiral arrangement."—Lord OXMANTOWN.

Spectrum continuous.

[No. 4315. 14 M. R.A. $17^{h}\ 30^{m}\ 16^{s}$. N.P.D. $93^{\circ}\ 9'\ 25''$. Cluster; bright; well resolved.]

Spectrum continuous.

[No. 4357. 3719 h. 199 H. II. R.A. $17^{h}\ 54^{m}\ 13^{s}\cdot 9$. N.P.D. $98^{\circ}\ 56'\ 37''\cdot 3$. Pretty bright; pretty large; round; partially resolved.]

Spectrum of the central, brighter part of the nebula continuous. As far as the light permitted, the marginal portion of the nebula was also examined, and appeared to give a continuous spectrum.

[No. 4437. 2019 h. 11 M. R.A. $18^{h}\ 43^{m}\ 37^{s}\cdot 2$. N.P.D. $96^{\circ}\ 26'\ 7''\cdot 6$. Cluster; very bright.]

"Stars curiously broken up into groups."—Lord OXMANTOWN.

The continuous spectra of all the brighter stars of this cluster were separately visible. When the clockwork of the equatoreal was stopped, an interesting spectacle was presented by the flashing in rapid succession of the linear spectra of the minute stars of the cluster as they passed before the slit.

In no part of the cluster was any trace of bright lines detected[†].

[No. 4441. 3762 h. 47 H. I. R.A. $18^{h}\ 45^{m}\ 29^{s}\cdot 2$. N.P D. $98^{\circ}\ 52'\ 8''\cdot 5$. Cluster; well resolved.]

Spectrum continuous.

[No. 4473. Auw. N. 44. R.A. $19^{h}\ 4^{m}\ 4^{s}\cdot 8$. N.P.D. $89^{\circ}\ 11'\ 51''$. Pretty bright[‡].]

Spectrum continuous.

[No. 4485. 2036 h. 56 M. R.A. $19^{h}\ 11^{m}\ 7^{s}\cdot 2$. N.P.D. $60^{\circ}\ 3'\ 41''\cdot 6$. Cluster; bright; well resolved.]

Spectrum continuous. Suspicion of unusual brightness in the middle part of the spectrum.

---

[*] Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

[†] This absence of any indication of gaseous matter is in accordance with telescopic observation. D'ARREST remarks of this cluster, "Mit Verg. 11 zerfällt der Sternhauf in deutlich gesonderte gruppen mit leeren zwischenräumen."—Beobach. der Nebelflecken und Sternhaufen, p. 346.

Lord ROSSE observes:—"In such objects as clusters we find no new feature; nothing which had not been seen with instruments of inferior power."—Philosophical Transactions, 1844, p. 322.

[‡] "This is the nebula discovered by Mr. HIND on March 30, 1845. It was observed in May 1852 as a nebula of the first class; subsequently as 'pretty faint and diluted.' M. AUWERS found it 'surprisingly faint,' and of the second class at the highest."—Philosophical Transactions, 1864, p. 38.

[No. 4586. 2081 h. R.A. $20^h\,27^m\,19^s{\cdot}8$. N.P.D. 83° 3′ 41″·3. Bright cluster.]

Spectrum continuous.

[No. 4625. 2097 h. 52 H. I. R.A. $20^h\,54^m\,43^s{\cdot}8$. N.P.D. 74° 21′ 51″·7. Bright; pretty large; round; gradually brighter in the middle.]

"Round. Bright middle."—Lord Rosse[*].

Spectrum continuous.

[No. 4600. 2088 h. 15 H. V. R.A. $20^h\,39^m\,53^s$. N.P.D. 59° 47′ 14″·8. Pretty bright; *k* Cygni involved.]

"It is very long and winding, and runs northward from *k* full 2 fields' breadth (30″). The nebulosity is milky, and does not seem to arise from small stars in the Milky Way ill seen."—Sir John Herschel[†].

"This nebula resembles the Milky Way, and is full of dark uneven rifts or lanes. There are portions of its preceding edge clearly resolvable."—Lord Rosse[‡].

I was not able to obtain a satisfactory spectrum of the nebula. The spectrum of the involved star was carefully examined. No peculiarity was observed in the continuous spectrum of the star. I have, however, the impression that the spectrum of the star, from about F towards the more refrangible end, appeared bright relatively to the other part. This might arise from groups of dark lines in the less refrangible portion of the spectrum.

[No. 4760. 2149 h. 207 H. II. R.A. $22^h\,1^m\,37^s{\cdot}4$. N.P.D. 59° 20′ 35″·6. Bright; extremely resolvable.]

"There is no doubt this nebula is a cluster."—Lord Oxmantown.

Spectrum continuous.

[No. 4815. 2172 h. 53 H I. R.A. $22^h\,30^m\,39^s{\cdot}5$. N.P.D. 56° 20′ 5″·6. Bright; pretty large; suddenly much brighter in the middle[§].]

"Stars sparkling near centre."—Lord Oxmantown.

Spectrum continuous.

[No. 4821. 2173 h. 233 H. II. R.A. $22^h\,30^m\,44^s$. N.P.D. 66° 55′ 34″·6. Considerably bright; small; very suddenly much brighter in the middle, star 11th mag.]

Spectrum continuous.

[No. 4879. 2199 h. 251 H. II. R.A. $22^h\,53^m\,8^s$. N.P.D. 74° 46′ 10″. Pretty bright; very gradually brighter in the middle.]

Spectrum continuous.

[No. 4883. 2201 h. 212 H. II. R.A. $22^h\,54^m\,17^s{\cdot}6$. N.P.D. 60° 36′ 32″·2. Considerably bright; gradually much brighter in the middle; barely resolvable.]

"Centre almost certainly resolvable."—Lord Oxmantown.

The spectrum does not consist of one or two lines only. I believe that it is continuous.

The discovery by means of prismatic observation, that some of the nebulæ are gaseous in constitution, invests these objects with a new importance to the theories of cosmical science. A first consideration of these nebulæ would suggest that we have now evidence from observation of the existence of that primordial nebulous matter required by the theories of Sir WILLIAM HERSCHEL and LAPLACE[*]. But though it should be found ultimately that, in some of its forms, the theory of the development of aëriform matter into suns and planets is a true representation of the mode of formation of the universe, still it would show a want of the strict caution which experimental science demands in the interpretation of observed facts, to explain the phenomena presented by the gaseous nebulæ in connexion with the requirements of a theory which at present is not more than a speculation. In a paper "On the Spectrum of the Great Nebula in Orion[†]," I stated, as the result of the observations which I had then made, the provisional opinion that the gaseous nebulæ may belong possibly to an order of cosmical bodies distinct from that represented by the sun and fixed stars. In this connexion it may be remarked that my examination of the light of Comet I. 1866 [‡] shows that a close relation probably exists between nebular and cometary matter.

---

[*] Philosophical Transactions, 1861, p. 734.

[†] Ibid. 1833, p. 468.

[‡] Ibid. 1861, p. 733.

[§] See drawing by Lord Rosse, Philosophical Transactions, 1861, Plate XXX. fig. 39.

As further contributions towards a future determination of the true rank and cosmical relations of these nebulæ, I proceed to give the results of some observations on the intensity of their light, and also measures of some of the planetary nebulæ.

§ IV. *On a Mode of determining the Brightness of some of the Nebulæ.*

As long as the nebulæ were regarded as aggregations of discrete stars separately invisible, it was not possible by any photometric estimation of the light from them which reaches the earth, to ascertain the intrinsic brilliancy of the suns of which the nebulæ were supposed to consist. For since these stars have no sensible magnitude even when separately visible, their intrinsic splendour could not be estimated from their brightness to an observer on the earth, so long as their distance from our system remained unknown.

Now, however, that the application of prismatic analysis to the light of the nebulæ has shown that some of these objects consist of luminous gas existing in masses which are probably continuous, though, indeed, in some cases, this aëriform matter appears to be aggregated into portions of unequal brilliancy, the intrinsic brightness of these nebulæ may be estimated from the earth, though their distance from us is unknown. The nebulæ are not points without sensible magnitude in the telescope, but present surfaces, in some cases, subtending a considerable angle. The brilliancy of a luminous surface, when beyond the earth's atmosphere, does not vary with its distance from the observer, except as it may be diminished by a possible power of extinction belonging to celestial space. For the diminution of brightness of a luminous surface, as it becomes more distant, takes place in the same proportion as the surface decreases in apparent magnitude; as long therefore as a distant object remains of sensible size in the telescope, the object retains its original brightness unaltered. If, therefore, the light of these nebulæ be compared with a luminous body on the earth, we can obtain approximately the intrinsic intensity of their light in terms expressing a proportion to the terrestrial light selected for comparison. The values of the intrinsic brilliancy of the nebulæ obtained in this way must be smaller than the true amount, because they are measures of the light after it has traversed an unknown extent of celestial space, and has passed through the earth's atmosphere. The amount by which, from these causes, the estimated brightness of the nebulæ would be too small must remain for the present unknown, since we have no data by which this loss could be even estimated*.

---

[*] A cosmical theory, which may perhaps be described as the converse of the nebular hypothesis, has been recently suggested by Professor E. W. BRAYLEY: see Proceedings of the Royal Society, vol. xiv. p. 120.

[†] Proceedings of the Royal Society, vol. xiv. p. 39.

[‡] Ibid. vol. xv. p. 5.

Notwithstanding these errors of unknown amount with which the results of a comparison of the nebulæ with a terrestrial source of light must stand affected, an attempt to discover, even approximately, the intrinsic brightness of the gaseous nebulæ has some importance in connexion with the physical constitution which prismatic analysis has shown these objects to possess. The coincidence of two of the three lines forming the spectra of some of the nebulæ, severally with a line of hydrogen and the brightest line of nitrogen, appears to indicate that they consist of aëriform matter. Highly transparent bodies, such as these gases are, emit when heated but a feeble light compared with that which would be radiated, at the same temperature, by more opake bodies. The invisibility of these nebulæ to the naked eye, though some of them are of considerable apparent size, shows that they possess a very feeble degree of luminosity†.

Besides these considerations, by means of similar photometric observations made at considerable intervals of time, it would be possible to ascertain whether the intrinsic brightness of the gaseous nebulæ is undergoing increase or diminution, or is subject to a periodic variation.

---

* In 1744 Chéseaux was led by theoretical speculations to assume that light is gradually extinguished in its passage through space. By somewhat similar reasoning Olbers (in 1823) assumed that a star loses the $\frac{1}{800}$ of its intensity in traversing a distance of space equal to that which separates Sirius from the sun.—Über die Durchsichtigkeit des Weltraums, Bode's Jahrbuch, 1826, s. 110–121.

The elder Struve, from an examination of Sir W. Herschel's telescopic gauges of the Milky Way, supposed that a star of the sixth magnitude has lost $\frac{7}{100}$ of its original intensity, a star of the ninth magnitude $\frac{29}{100}$, and the smallest star visible in Sir William Herschel's telescope $\frac{88}{100}$.—Études d'Astronomie Stellaire, p. 89.

A fundamental element of the reasoning by which Struve obtained these values was, that the stars are distant from our system in the inverse ratio of their apparent brightness. Since, however, the stars to which observation assigns the largest parallax, 61 Cygni and α Centauri, are less bright than other stars, in which no parallax, or a much smaller one only, has been detected (not to refer to what may be regarded as an exceptional case, the great inequality in magnitude of some binary stars), this assumption that the apparent brightness of stars depends alone upon their distance, has been shown not to be true in the cases in which it has been confronted with observation.

† "It is evident that the intrinsic splendour of their surfaces, if continuous, must be almost infinitely less than that of the sun."—Sir John Herschel, Outlines of Astronomy, p. 646, 7th edit.

For the purpose of making these observations I had constructed, by Mr. G. DOLLOND, an instrument in which are combined two forms of apparatus contrived by the Rev. W. R. DAWES, F.R.S., and described by him under the names of "An aperture-diminishing eyepiece," and "A Photometer of Neutral-tint Glass*."

This instrument, which is adapted to the eye-end of my achromatic telescope, consists essentially, first, of a diaphragm drilled with small holes moveable within the focus of the telescope, which diminishes the aperture of the telescope in proportion as it is advanced towards the object-glass; and secondly, of two graduated wedges of neutral-tint glass, which slide in front of the convex lenses with which the focal image is viewed. The aperture in the diaphragm which was used in the following observations has a diameter of 0·06 inch. The diaphragm is moved by a screw, and its position is read off upon a scale divided into tenths of an inch. The photometer wedges are 4 inches in length and divided into forty parts.

The observations were made in the following way.

The diaphragm was placed so that all the pencils from the object-glass passed through the small aperture without diminution. The nebulæ were viewed through the wedges of neutral-tint glass. These were made to slide before the eye, until the exact part of one of the wedges was found, at which the nebula was extinguished.

On August 25, 1865, a night of more than usual clearness, several estimations were made of each of the three nebulæ, No. 4628. 1 H. IV., the annular nebula in Lyra, and the Dumb-bell nebula. In each case the estimation applies to the brightest part of the nebula.

The source of light selected as a standard of comparison was a sperm candle of the size known as "six to the pound."

The rate of burning of this candle on three occasions was—

August	26	.	35 minutes	lost in	weight	132 grs.	=157·8 grs.	per hour.
,,	31	.	38 ,,	,,	,,	142 grs.	=160·8 grs.	,,
September	7	.	41 ,,	,,	,,	148 grs.	=157·8 grs.	,,

It was found necessary to diminish greatly the light of the candle in order to bring it within the range of comparison afforded by the moveable diaphragm.

For this purpose a thick plate, with parallel sides, of neutral-tint glass was placed before the flame of the candle. An examination of the neutral-tint glass with a prism showed that the absorptive power of the glass for all refrangibilities in the brighter portions of the spectrum was very nearly uniform. The amount of diminution of the light of the candle effected by the plate of neutral glass was measured by a BUNSEN'S photometer. When the light passed through the neutral glass, the candle required to be placed at a distance of 6·5 inches to cause the ungreased central spot of the photometer to disappear. Without the glass, the disappearance took place when the candle was removed to a distance of 126·25 inches. The disappearance was viewed with a small telescope. The numbers adopted are the mean of several observations, the close accordance of which showed that the fixed light behind the screen had remained of constant intensity. The ratio of the squares of the distances shows that the light of the candle was reduced by the neutral-tint glass to the $\frac{1}{377}$ part of its original intensity.

---

* Monthly Notices, Royal Astronomical Society, vol. xxv. p. 229.

The candle, placed in a lantern and screened by the neutral-tint glass, was fixed on the roof of a house at a distance of 440 yards from the observatory*. It was desirable that the candle should be at some distance, in order that its image in the telescope should be formed at nearly the same distance from the object-glass as the images of celestial objects. Besides, it was convenient that the flame of the candle should appear small, when viewed with the convex lens, magnifying on the telescope 101 diameters, with which the nebulæ had been observed.

The image of the flame of the candle in the telescope was viewed through the same parts of the wedges of neutral-tint glass at which the nebulæ had been observed to become invisible. By means of the moveable diaphragms, and also independently by means of diaphragms placed before the object-glass, the apertures of the object-glass were found at which the flame of the candle became extinguished at the parts of the wedges at which the nebulæ had been observed to disappear.

	Sept. 7, 1865.	Jan. 19, 1866.
Aperture corresponding to nebula in Lyra . .	2·09 inches.	2·00 inches.
„ „ Dumb-bell nebula . .	1·06 inch.	1·20 inch.
„ „ Nebula No. 4628. 1 H. IV.		4·0 inches.

Taking into consideration the circumstances of the observations, I adopt for the

Dumb-bell nebula an aperture of . . .	1·10 inch.
Annular nebula in Lyra an aperture of .	2·00 inches.
Nebular No. 4628 an aperture of . . .	4·00 inches.

The disappearance of the nebulæ with the neutral-tint glass wedges had been observed with the full aperture of the telescope (8 inches), therefore the ratios of the areas of the aperture corresponding to the diameters of 1·10 inch, 2·00 inches, and 4·00 inches, to the area of the full aperture of the telescope, will give the intensities of the nebulæ in terms of the candle screened with the neutral-tint glass. The results are—

Dumb-bell nebula . . . . $=\frac{1}{52}$
Nebula in Lyra . . . . $=\frac{1}{16}$
Nebula No. 4628 . . . . $=\frac{1}{4}$

of the intensity of the obscured candle.

The neutral-tint glass reduces the intensity of the candle to the $\frac{1}{377}$ part, therefore the intensities of the nebulæ in terms of the intensity of the unscreened flame of the sperm candle are—

---

* I gratefully acknowledge the assistance of my friend, Mr. S. B. Kincaid, F.R.A.S., who took the management of the candle.

Nebula No. 4628 . . . . $= \frac{1}{1508}$,
Annular nebula in Lyra. . . $= \frac{1}{6032}$,
Dumb-bell nebula . . . $= \frac{1}{19604}$.

It may be remarked, in connexion with these values of the intensity of the light of these nebulæ, that nebula No. 4628 gives a spectrum of three bright lines, and also a faint continuous spectrum. The nebula in Lyra and the Dumb-bell nebula give one bright line only.

§ V. *Measures of some of the Nebulæ.*

If great physical changes, such as subsidence and condensation, of the magnitude necessary for the conversion of the nebulæ into suns are taking place in these objects, an indication of the advance of these processes might perhaps be obtained by measurements, taken at considerable intervals, of such of the nebulæ as are suitable for this purpose. There are several of the planetary nebulæ which give a gaseous spectrum, which in telescopes of moderate power have disks sufficiently well defined for micrometric measurement. Measures of these nebulæ would be comparable with future measures obtained with telescopes of similar power.

Some months since I invited the Rev. W. R. Dawes, F.R.S., to take measures of the diameters of several of these objects. Ill health has unfortunately prevented him from measuring more than one nebula, No. 4234, 5Σ. Mr. Dawes writes, "So bright and yet so imperfectly defined, like the heads of some comets. The moon was near the horizon, yet I found that I could get hold of more of it with high powers than with lower. It appeared rather suddenly to fade away at the edges, and to have a sort of faint halo round it, which, however, was not distinctly separate from the brighter centre. I obtained four sets of measures of the diameter which was parallel to the equator; but thought that the form was rather elliptic, the equatorial diameter being the greater. The four sets were obtained with powers 148, 218, 292, and 382; that with 148 appearing to be far less certain than the others. The illumination of the field necessary to show the wires with power 148 seemed to diminish the visibility of the nebula more than did the increase of power; with which the wires were sufficiently seen with much less illumination. The results were—

$$\left.\begin{array}{lrl} \text{With power} & 148 \text{ diam.} & =14''\cdot 23 \\ \text{,,} & 218 \quad \text{,,} & =15\cdot 76 \\ \text{,,} & 292 \quad \text{,,} & =15\cdot 70 \\ \text{,,} & 382 \quad \text{,,} & =16\cdot 23 \end{array}\right\} \text{Mean of all } 15''\cdot 5.$$

"Mean of the three higher powers =15″·9, which I consider worthy of much more confidence. I could not see the fainter halo sufficiently well with any illumination to get safe measures of it. These results refer to the brighter disk only."

Measures of this nebula by former observers—

1833, diam. = 8″ Sir John Herschel[*].
1856, March, diam. = 6 D'Arrest } [†]
1856, June, diam. = 8 D'Arrest }
1864, August, diam. = 9·6 Schultz } [‡]
=14·5 Auwers? }

Nebula No. 4514. 2050 h. 73 H. IV. I made careful measures of this object on two occasions. Wire micrometer with dark ground illumination.

1865. Nov. 25. Power 333. Mean of six measures 31″·06.

1865. Dec. 15. Power 680. Mean of three measures 30″·66.

I think the measures of Dec. 15 are entitled to more confidence than those of Nov. 25. I should prefer to take as the most probable value—Diam. in R.A. =30″·8.

1833. Diam. in R.A.=45″·5. Sir John Herschel[§].

1864. Diam. in R.A.= 0′·4. Schultz[||].

---

[*] Philosophical Transactions, 1833, p. 458.

[†] Beobachtungen der Nebelflecken und Sternhaufen, p. 341.

[‡] Astronom. Nachrichten, No. 1541, p. 70.

[§] Philosophical Transactions, 1833, p. 464.

[||] Astronom. Nachrichten, No. 1541.

Fig. 4 b.

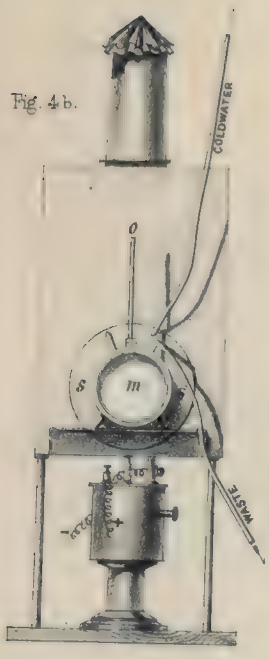


Fig. 4 a.

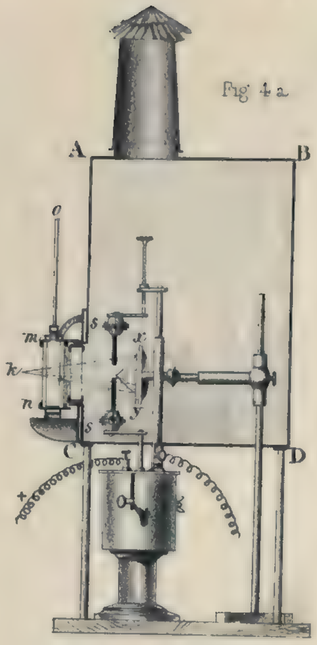


Fig. 5.

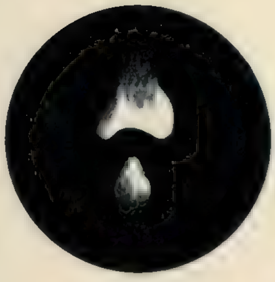


Fig. 6.

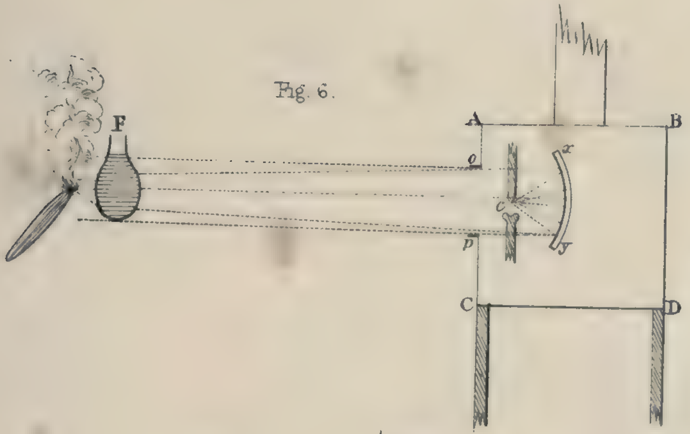


Fig. 7.

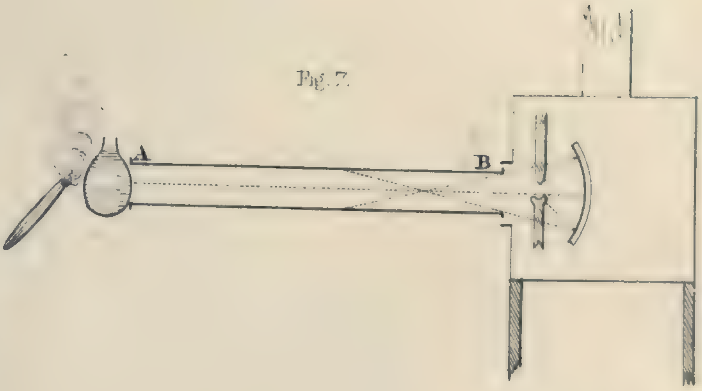


Fig. 8.

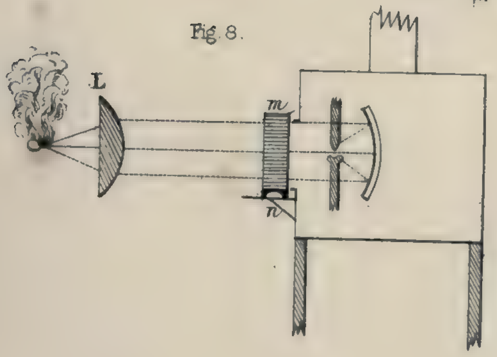


Fig. 9.

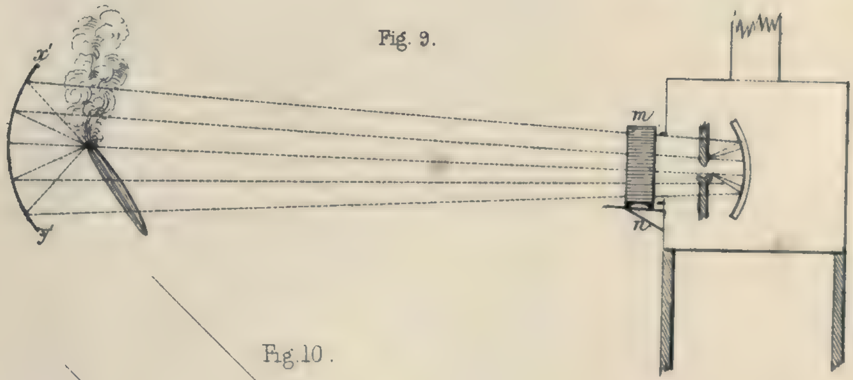
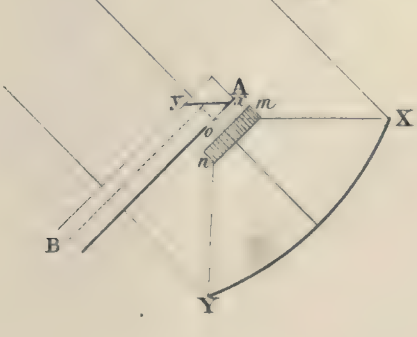
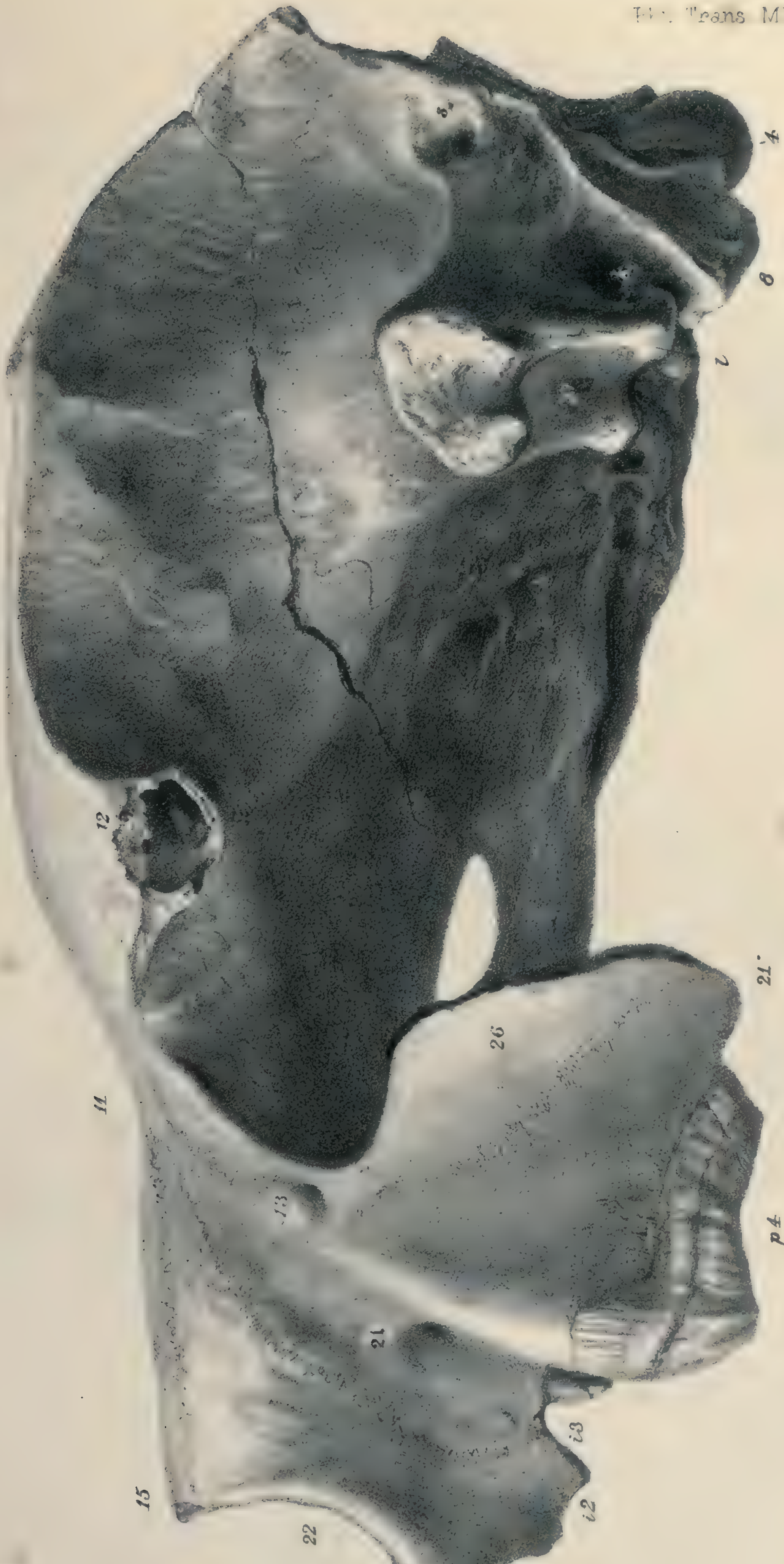


Fig. 10.

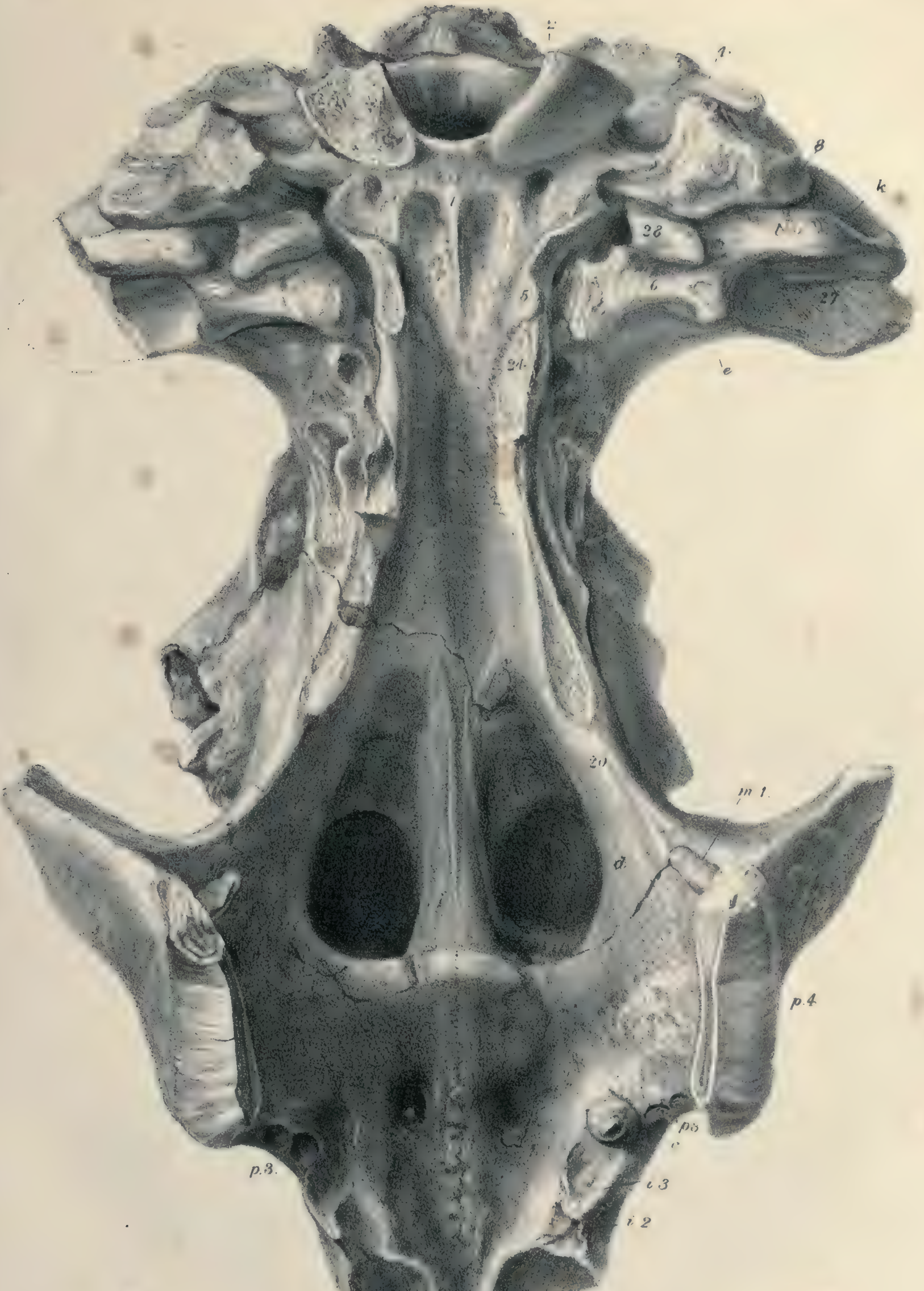


Phil. Trans. MDCCCLXXVI. Plate II.



J. W. Dinkel del. et lith.

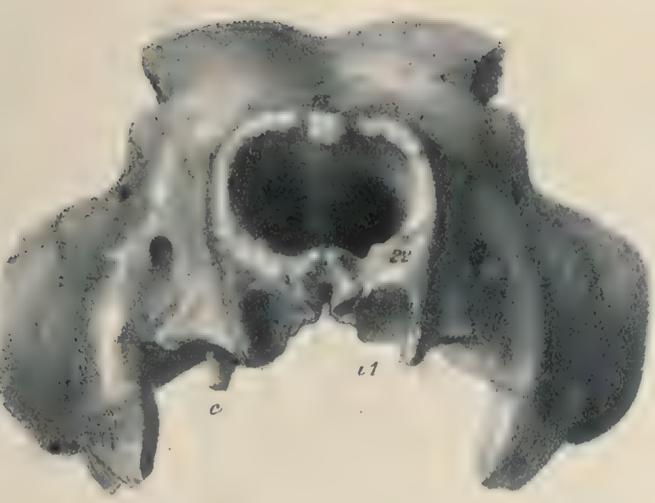
[illegible]



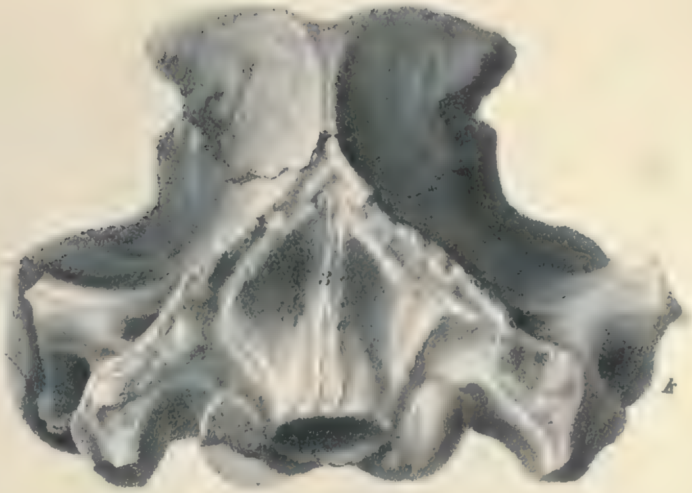
J. W. [illegible] del. et lith.

M & N [illegible] imp.

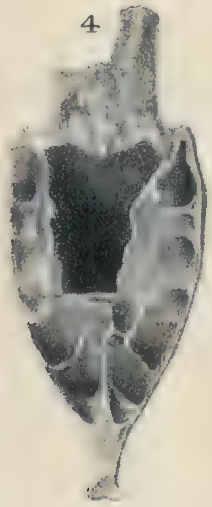
1



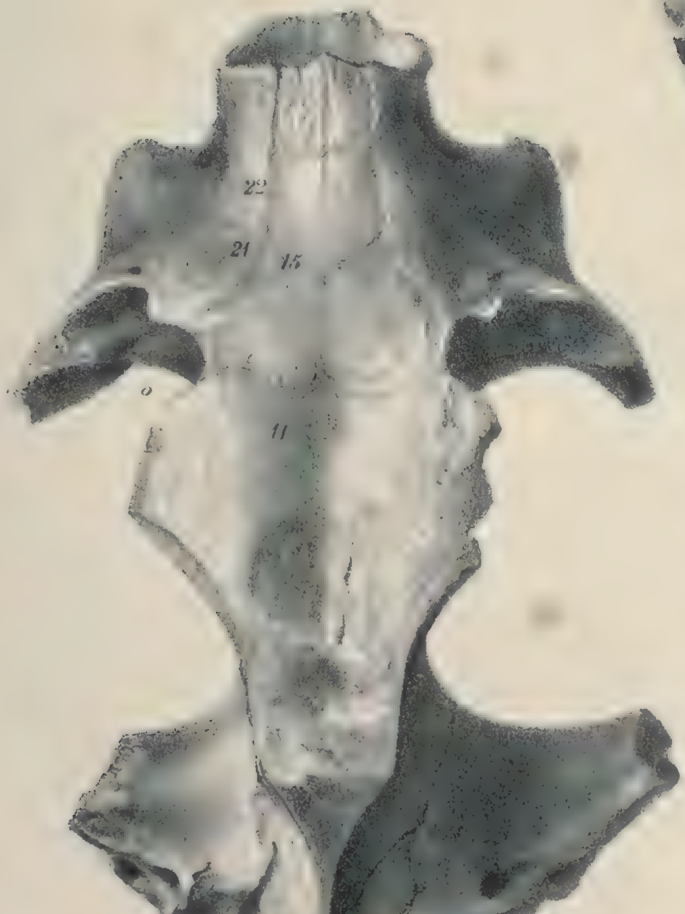
2



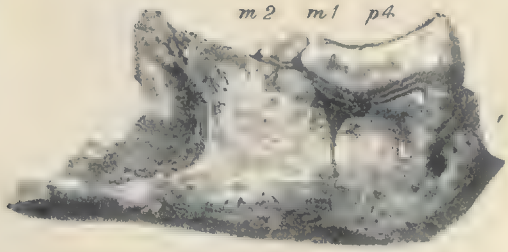
4



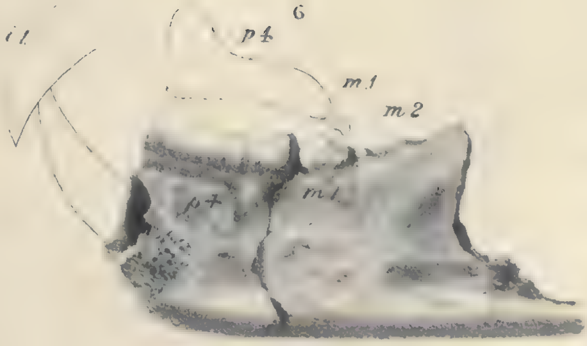
3



5

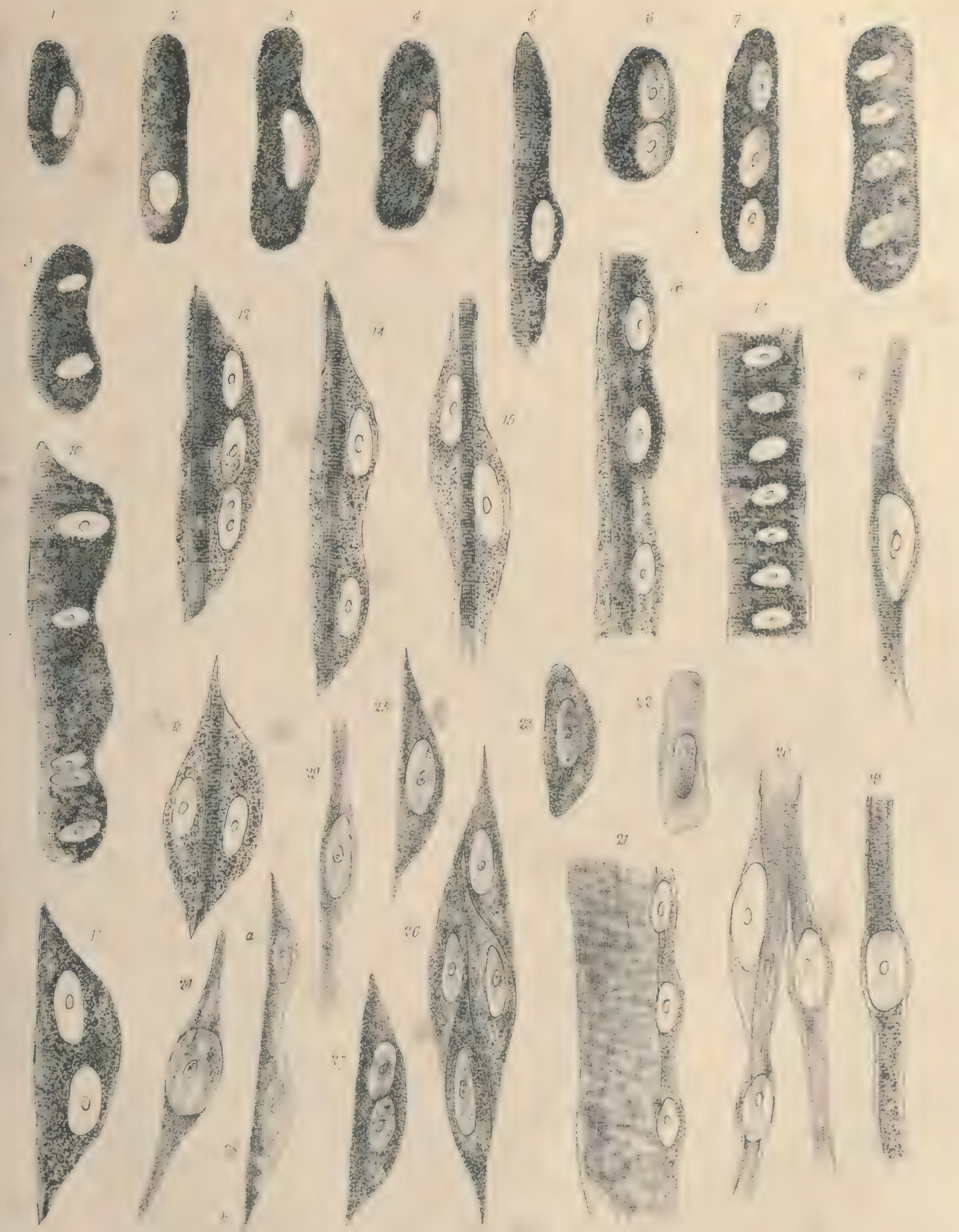


6



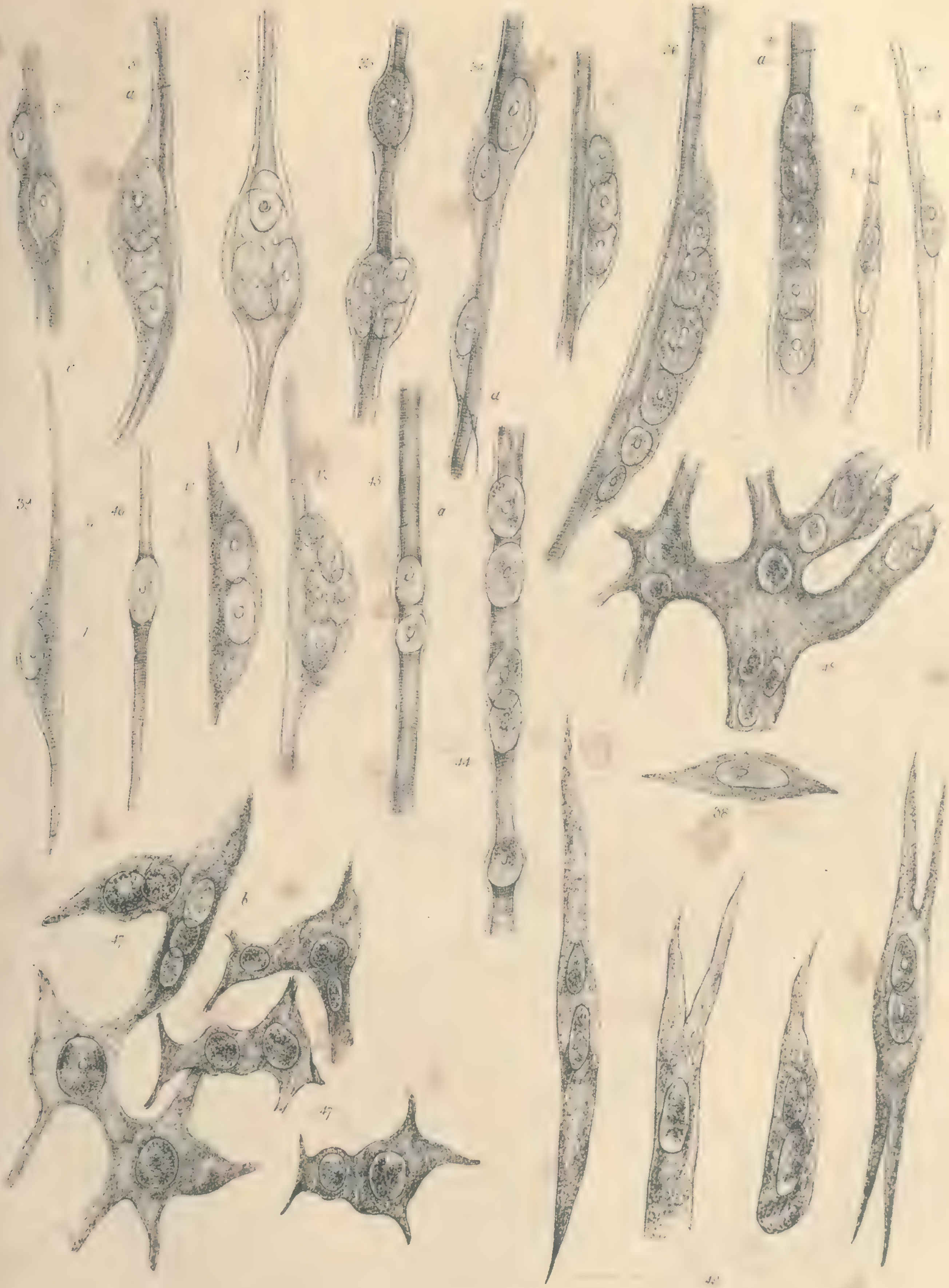
J. W. Lowne del. et lith.

M & N. Hanhart imp.



[illegible] ad Nat. del. [illegible] [illegible]

Development of Striated Muscular Fibre



Degenerating Striated Muscular Fibre

Fig 6

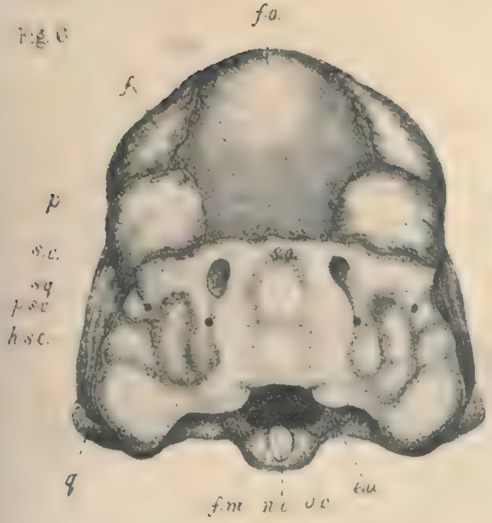


Fig 3

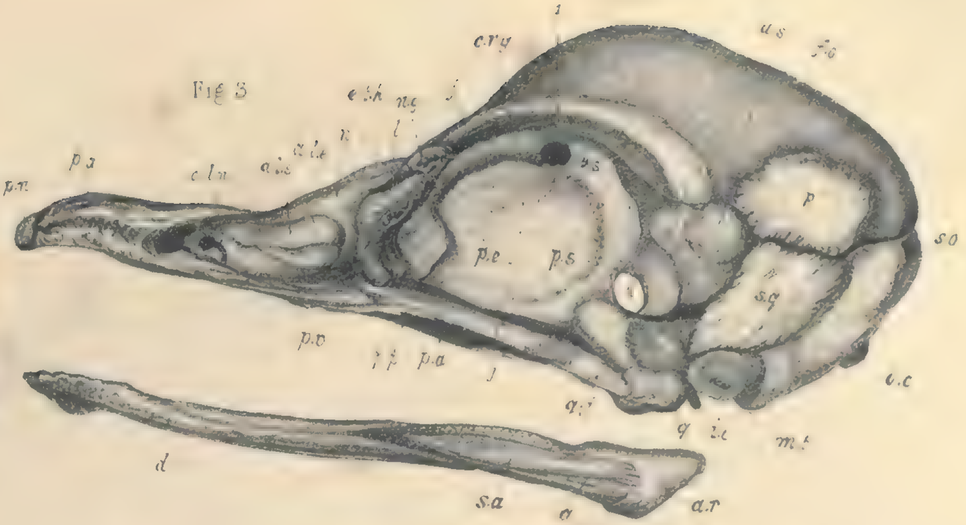


Fig 1

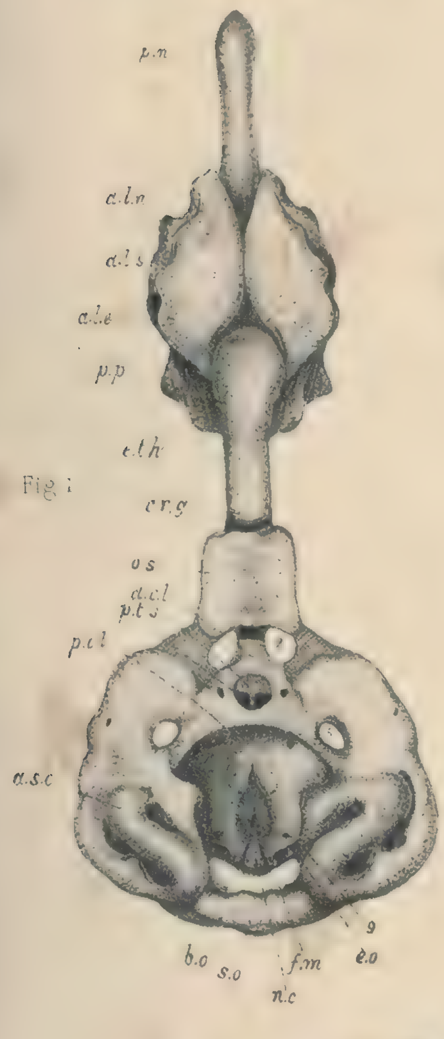


Fig 4

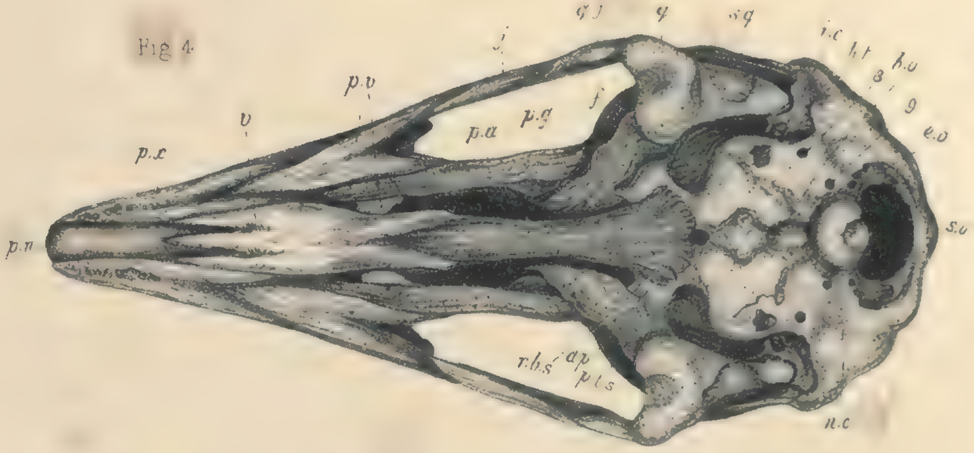


Fig. 5

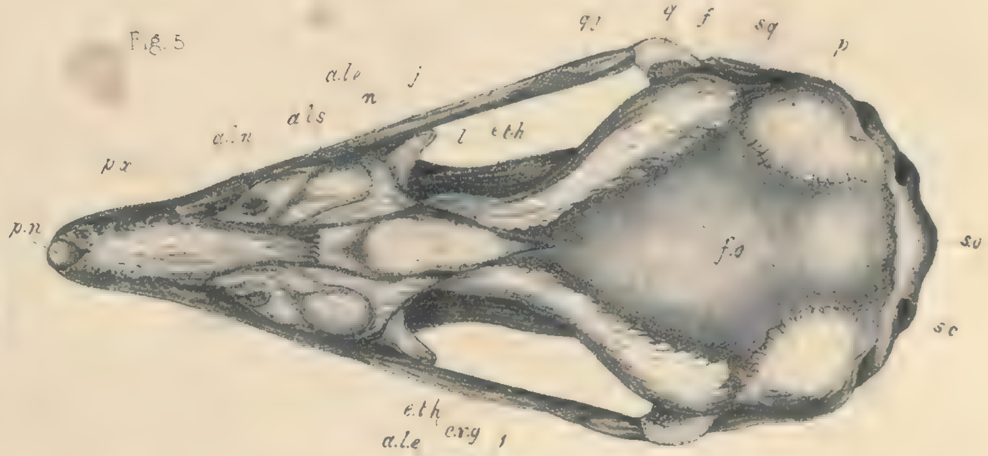


Fig 7

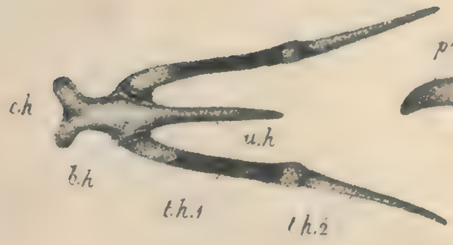
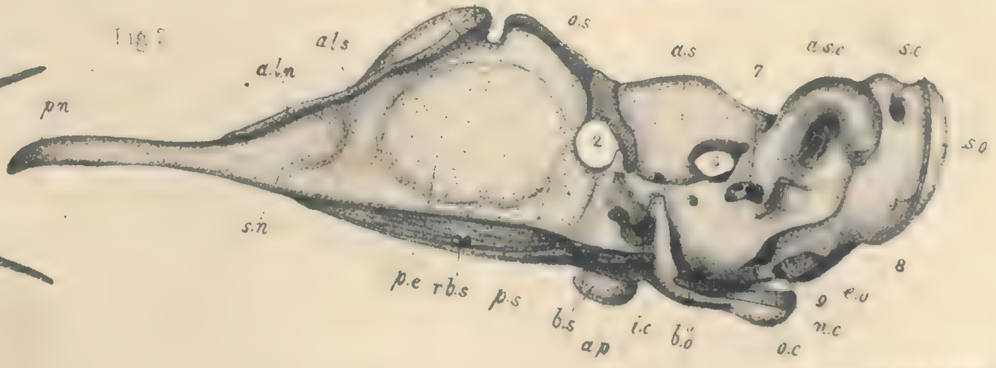


Fig 2



[illegible] ad Nat. del.

J. Basire Lith.

[illegible] lith.

[illegible]

[illegible]

Fig. 6

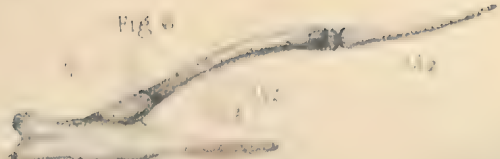


Fig. 1

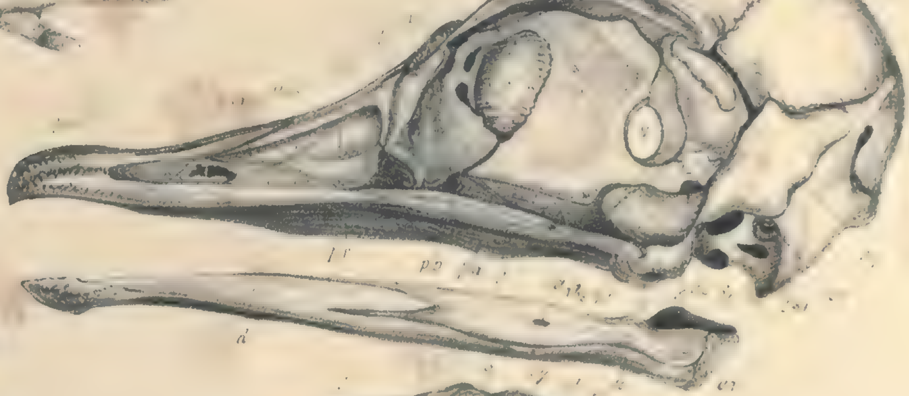


Fig. 4

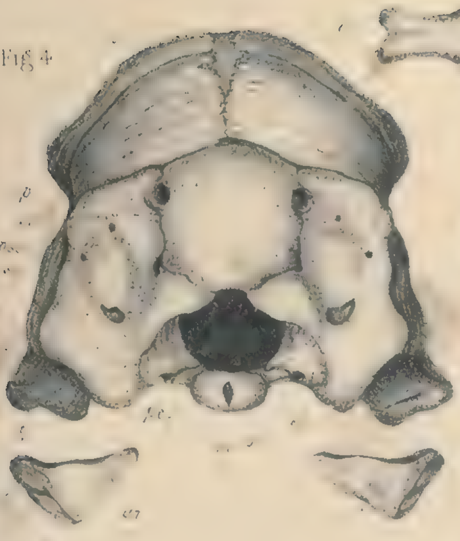


Fig. 2

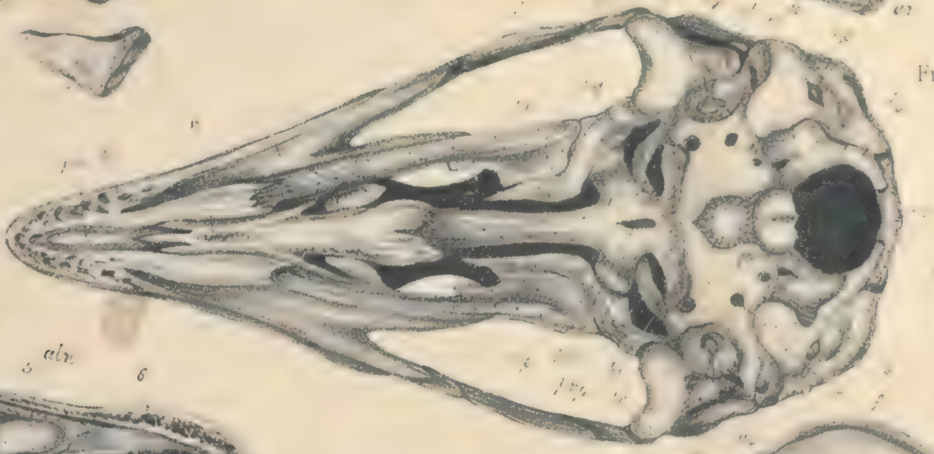


Fig. 3

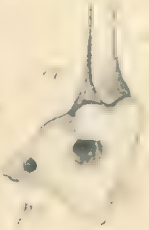


Fig. 7

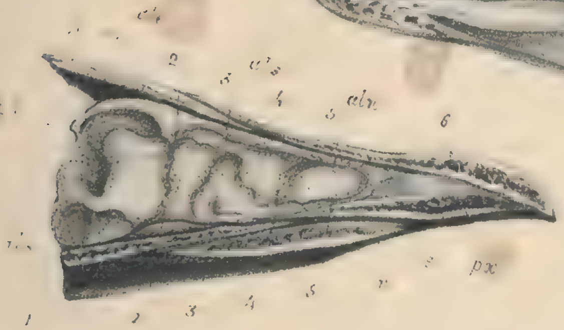


Fig. 5

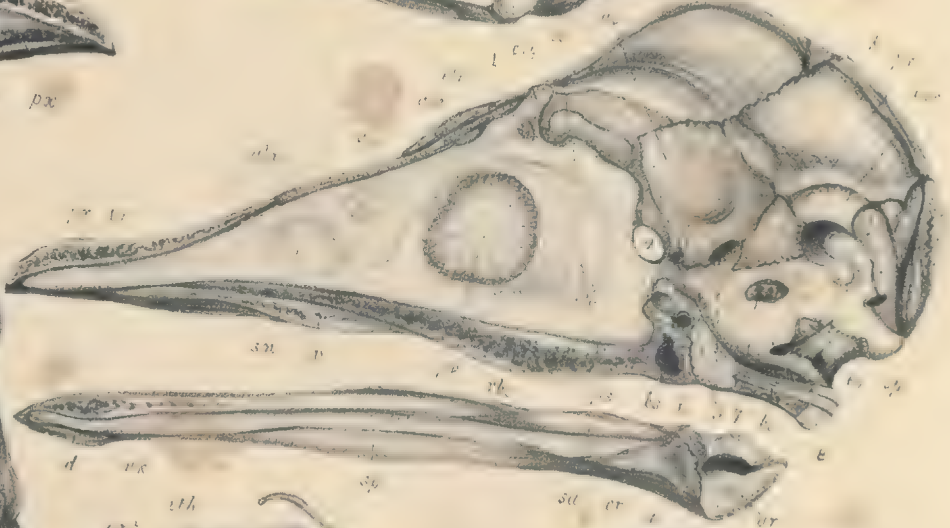


Fig. 8

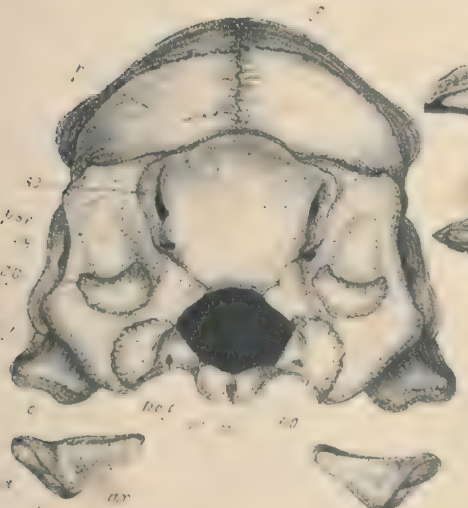


Fig. 11

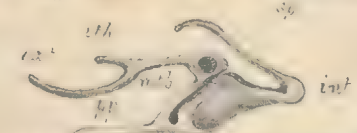


Fig. 9

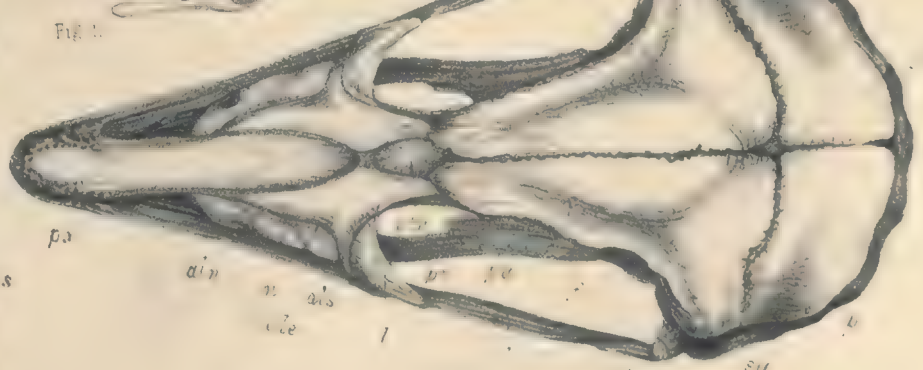
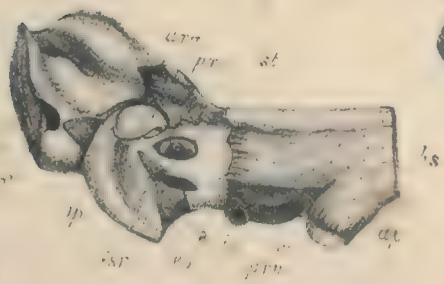


Fig. 10



W. K. Parker ad Nat. del.

J. Basire lith.

F. M. Williams [illegible] lith

[illegible]

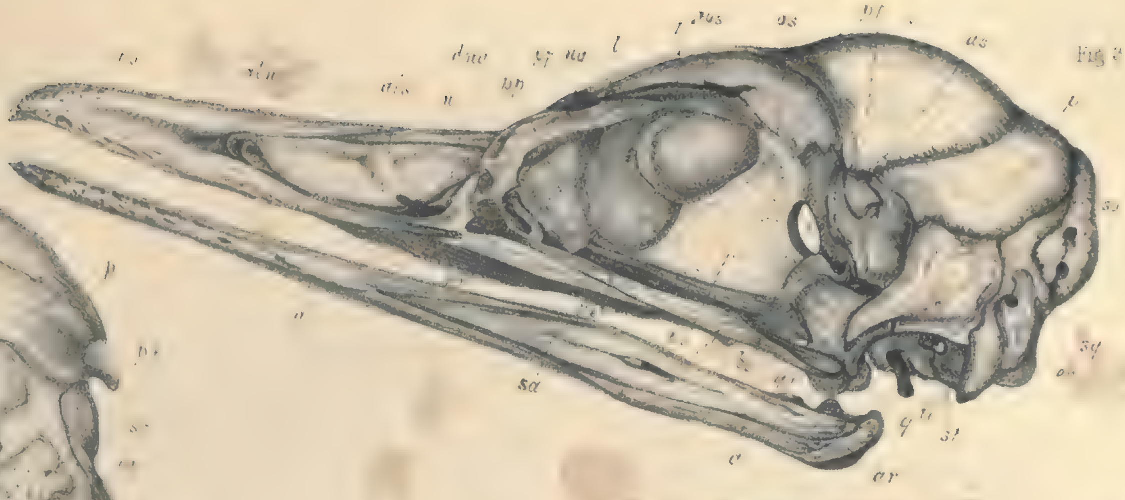
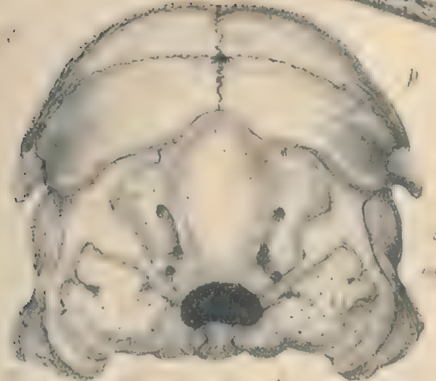


Fig 3



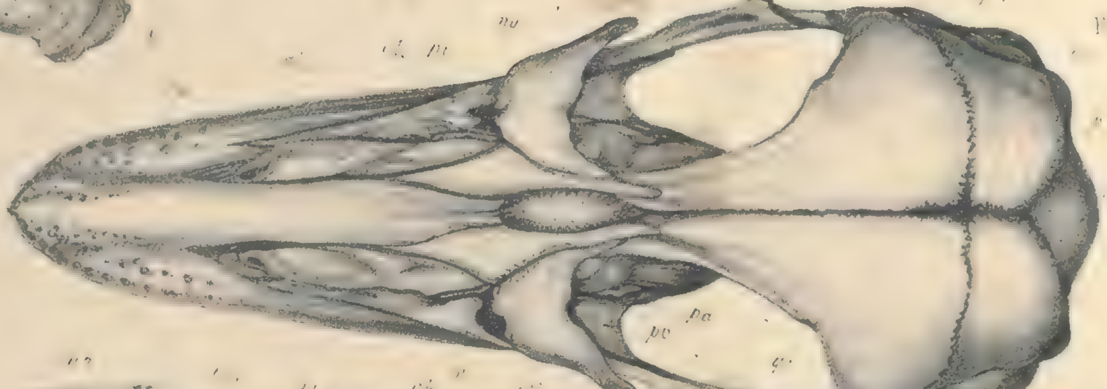


Fig 5

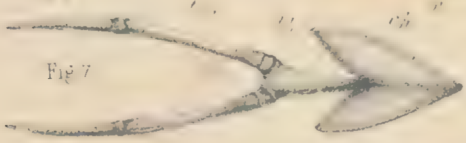


Fig 7

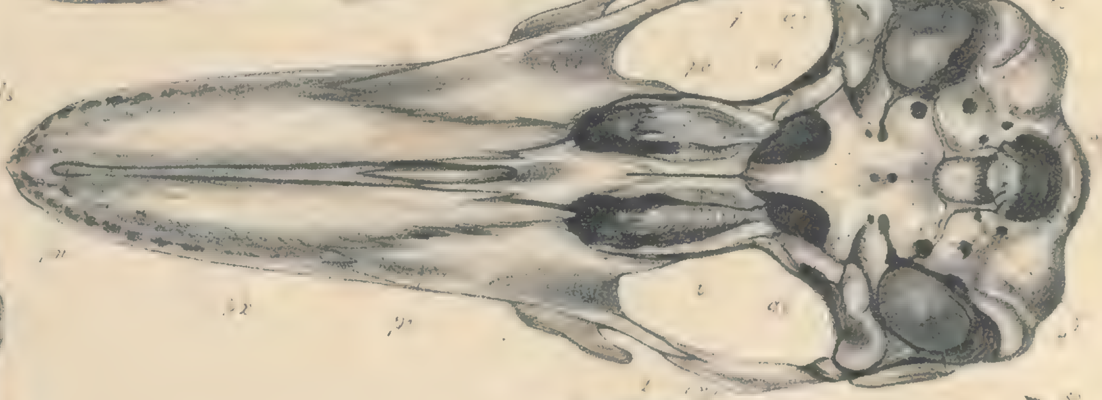


Fig 4

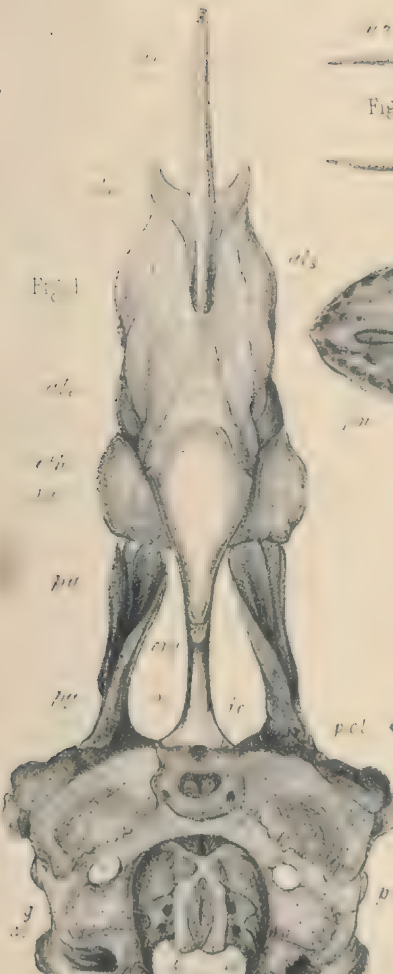


Fig 1

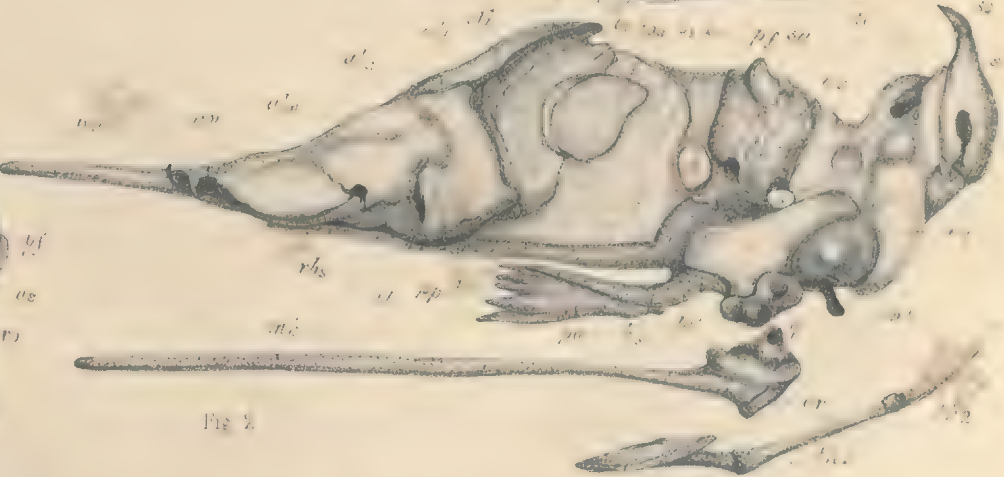
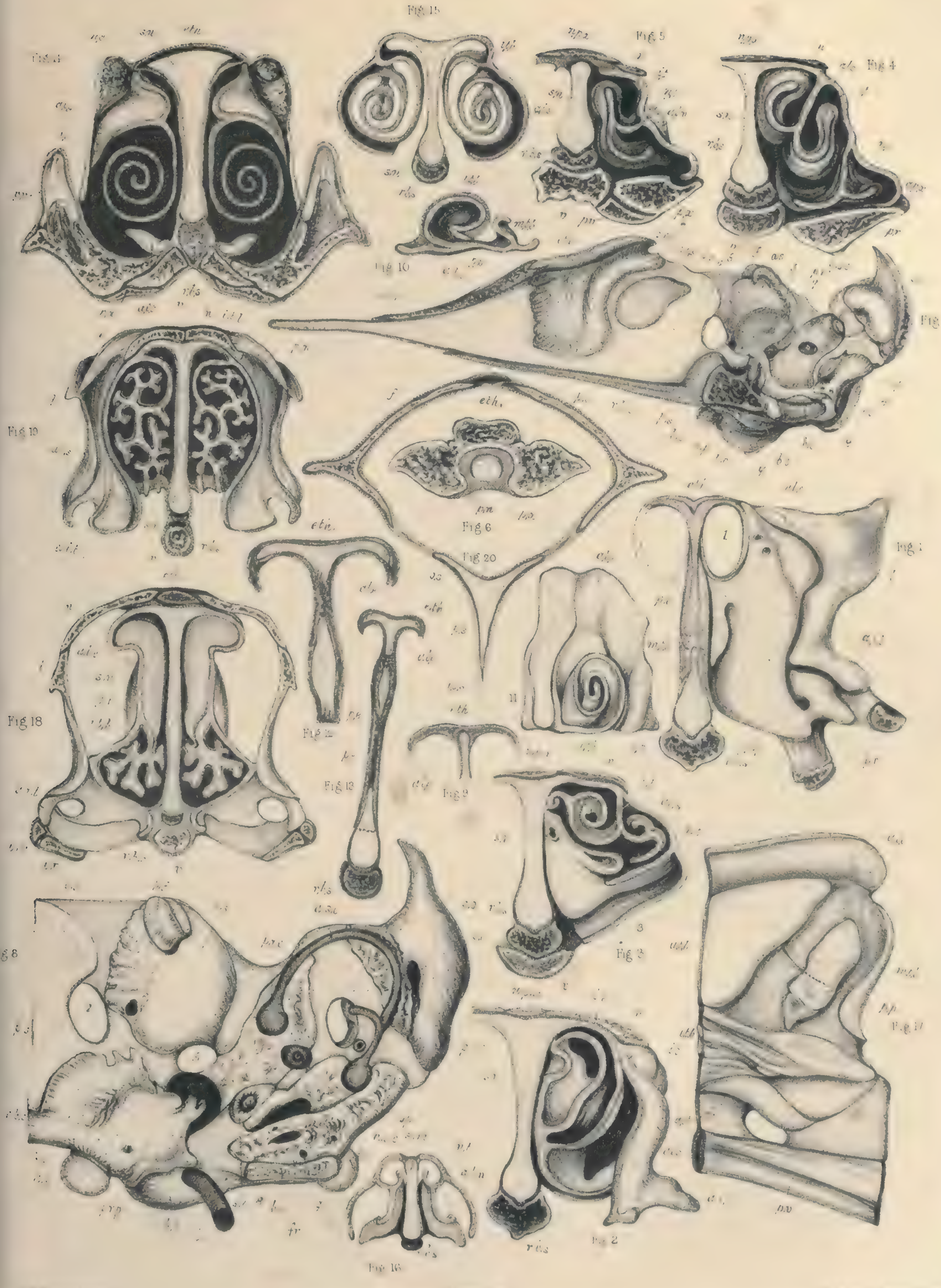


Fig 2

W. K. Parker ad Nat. del. [illegible] [illegible]

[illegible]



W.K. Parker del. [illegible] [illegible]

[illegible] 6 Struthio [illegible] Rhea americana var. 4 & 6 Figs 17–20 Casuarius Bennettii 4 Diam

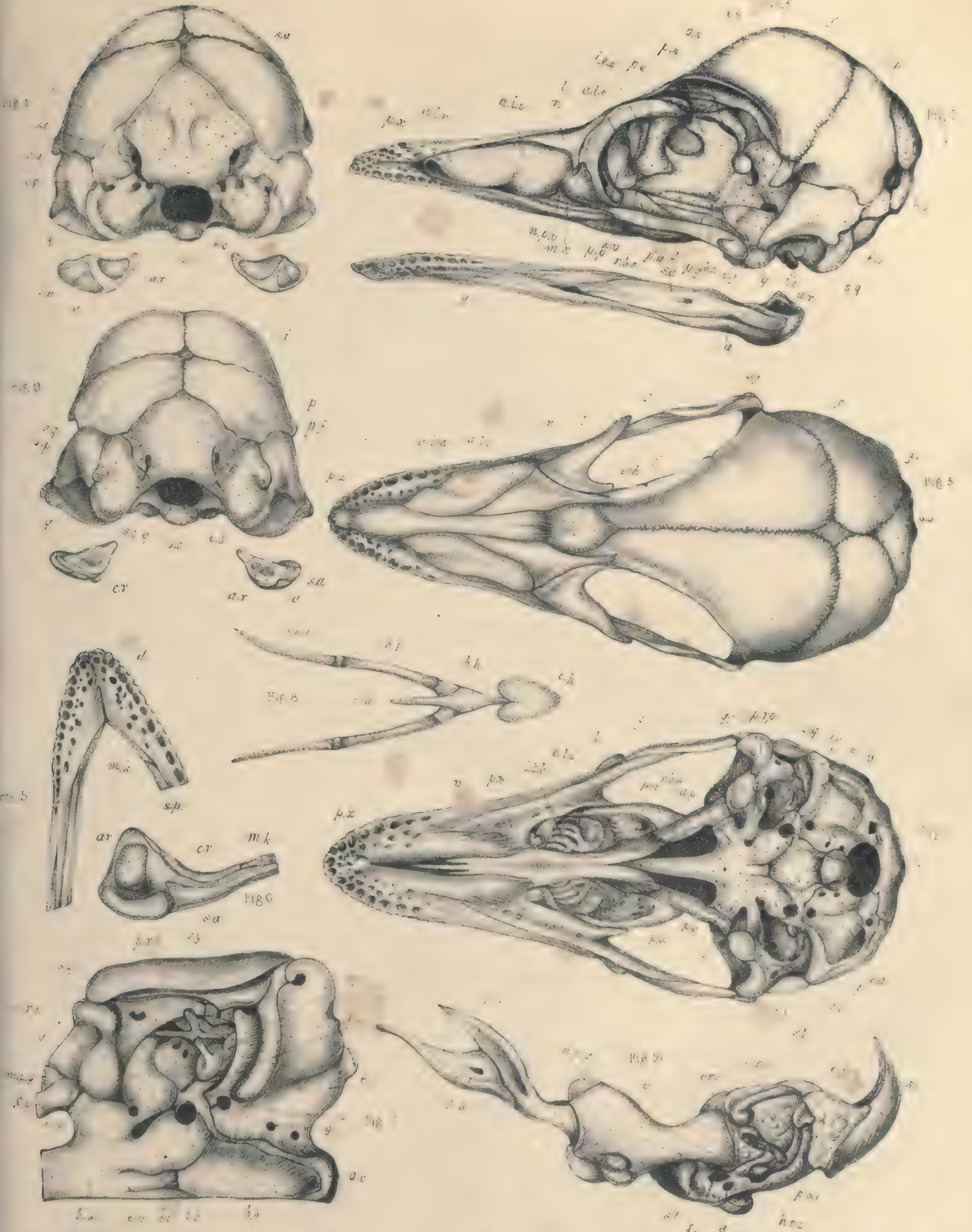
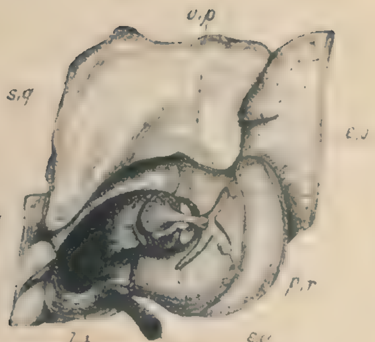
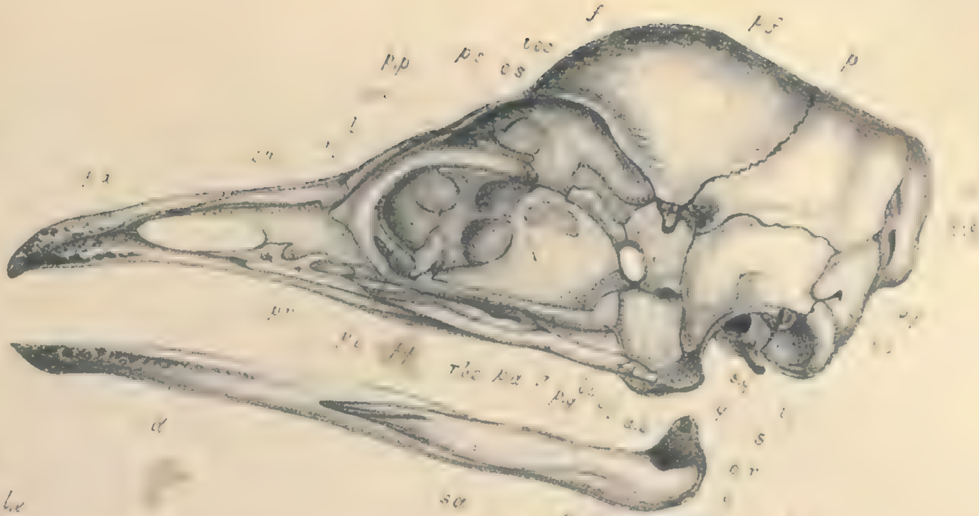
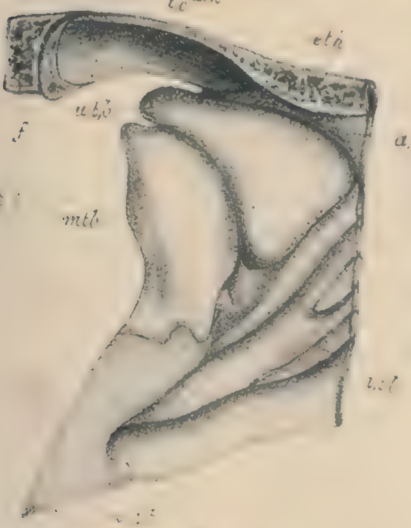


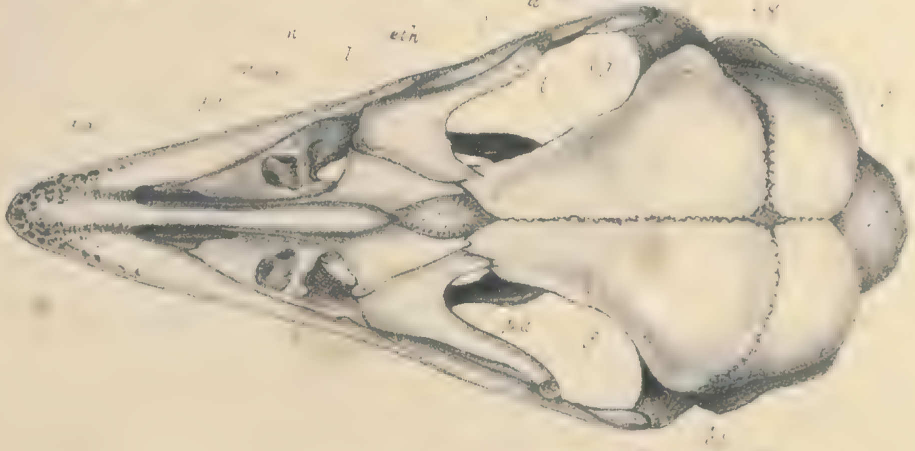
Fig 1
s.a
s.o
e.o
a.r
Fig 2
p
p.f
sq
s.o
e.o
c.r
a.r
s.a
d
Fig 7
p.s
o.s
i.o.s
p.e
a.l.e
a.i.s
l
n
p.x
n.p.v
m.x
p.g
r.b.s
p.a
sq
q
a.r
f
p
Fig 3
p.x
n
e.h
f
s.o
Fig 8
b.h
c.h
Fig 5
d
m.k
s.p
ar
c.r
m.k
Fig 6
s.a
p.x
v
p.x
l
a.l.e
p.p
q
p.t
Fig 4
b.o
e.o
Fig 9
p.sc
fr
h.sc
o.c

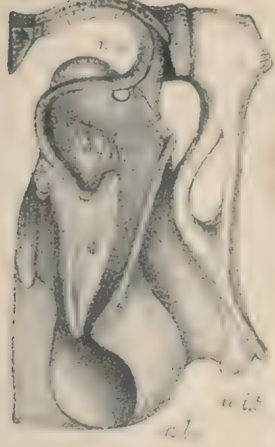
1–8. [illegible]

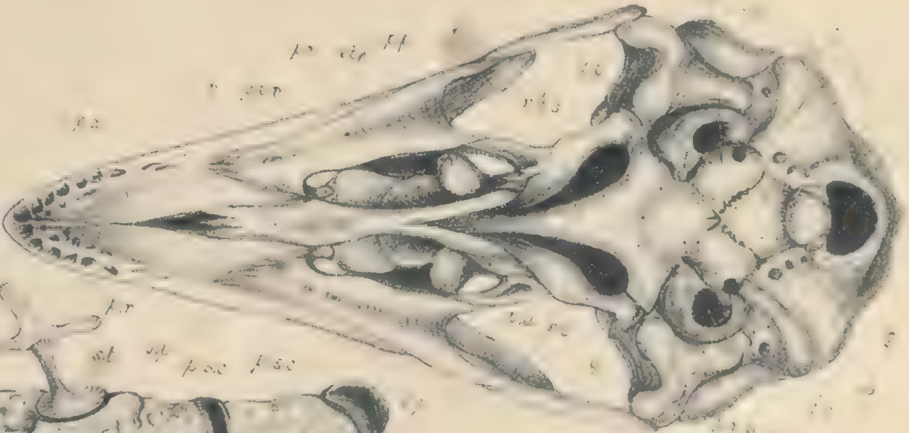

o.p
Fig 4
s.q
e.s
q
p.r
l.t
i.c
a.n
e.q

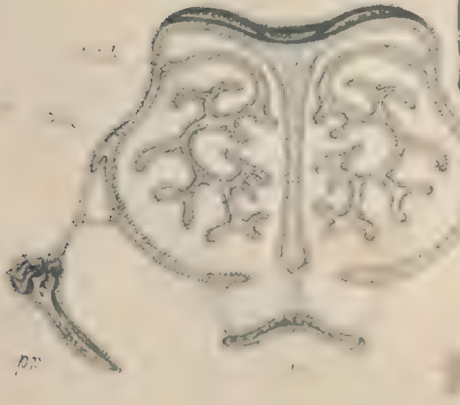

f
p.f
p
p.p
p.s
b.o
o.s
l
p.x
p.r
p.t
p.f
r.b.c
p.a
p.g
o.s
q
s
o.r
d
s.a
a

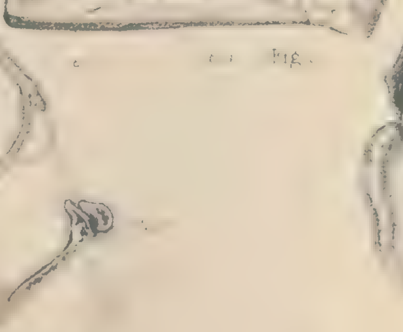

eth
u.t.b
f
a.b.c
Fig 5
mtb
t.c.l

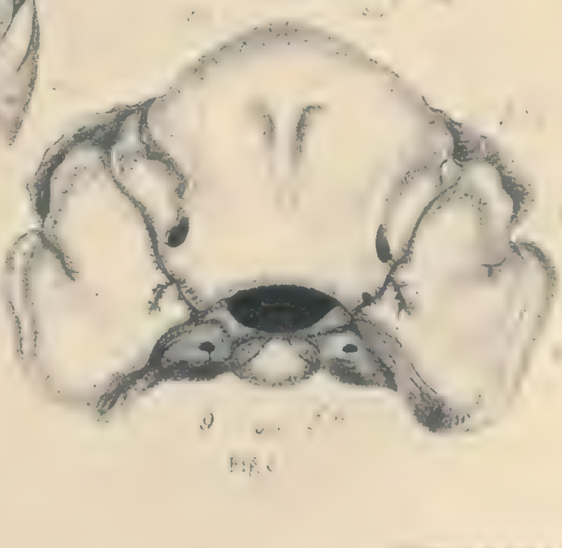

n
l
eth
p.c


u.t.b
a.b.


p.t
p.f
p.x
r.b.s
g


n
p.x
pr


sq
p.r
st
p.sc
f.sc
p.ro
Fig.


g
Fig.6

W.K. [illegible] del. [illegible] [illegible]

[illegible]

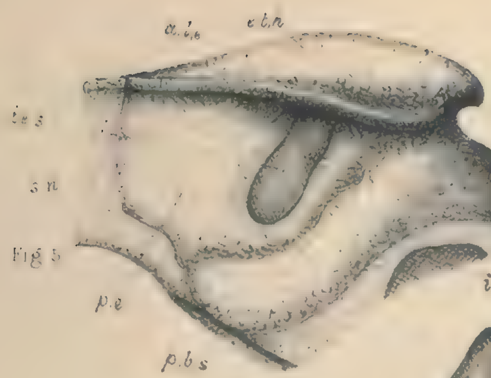


Fig 5

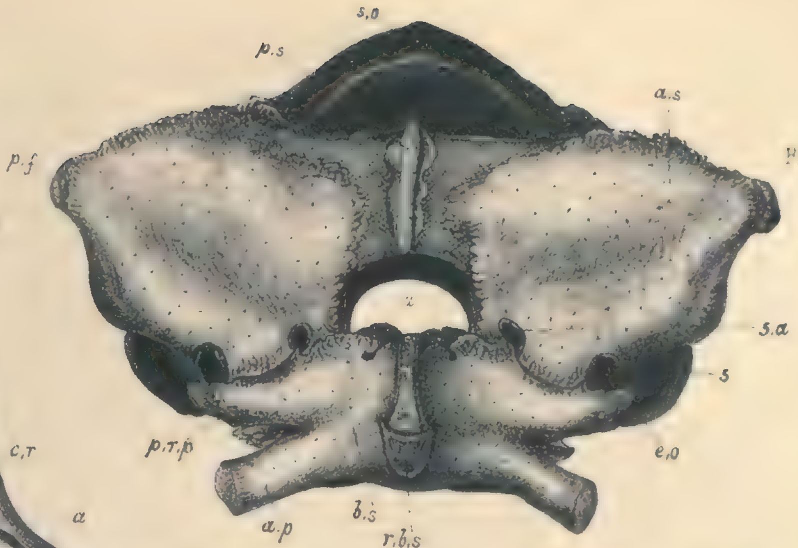


Fig. 7

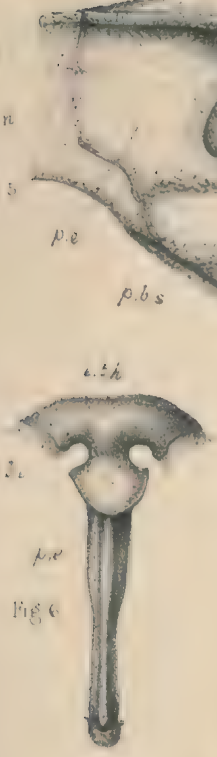


Fig 6

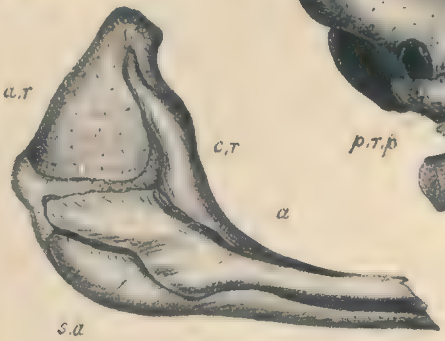


Fig 11

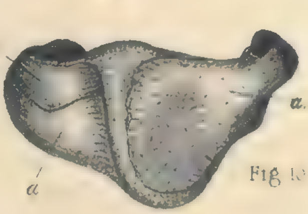


Fig 10

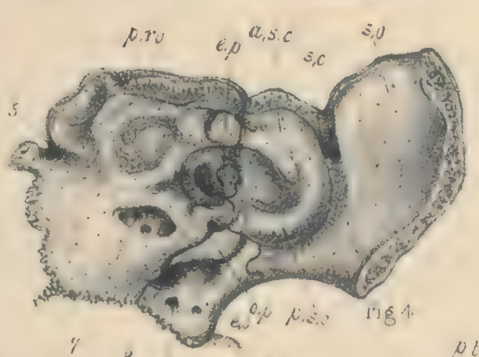


Fig 4

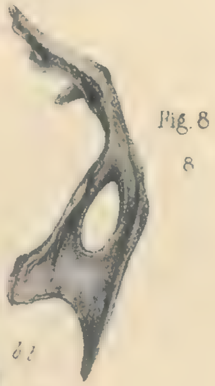


Fig. 8

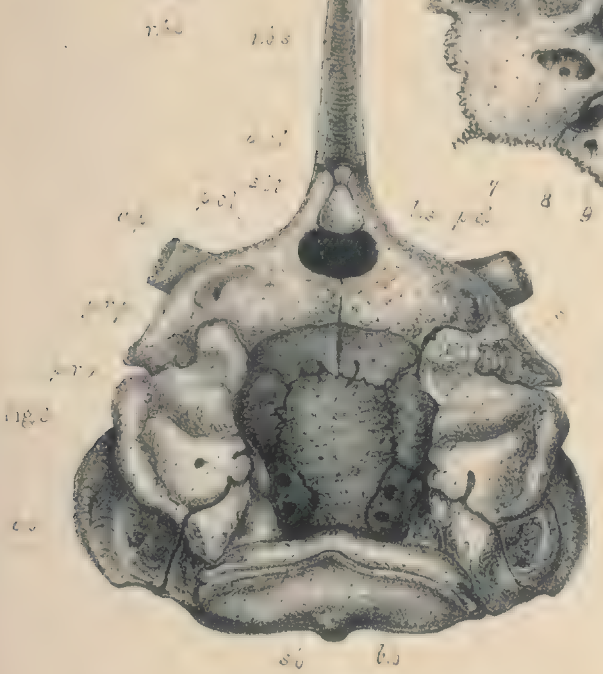


Fig 2

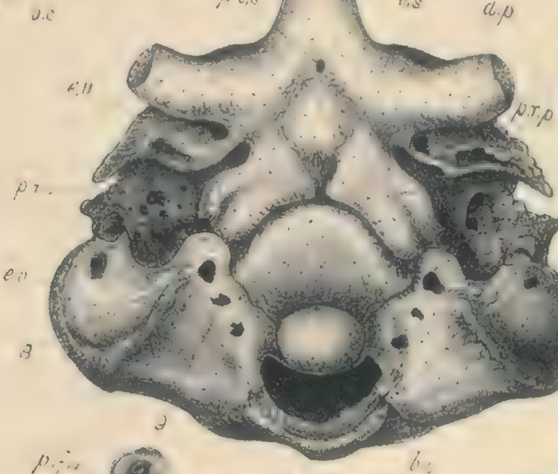


Fig 1

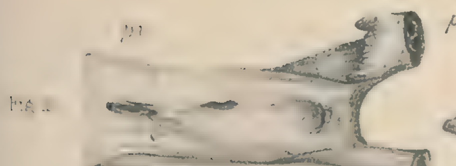


Fig 3

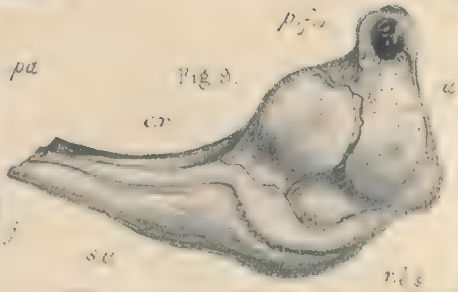


Fig 9.

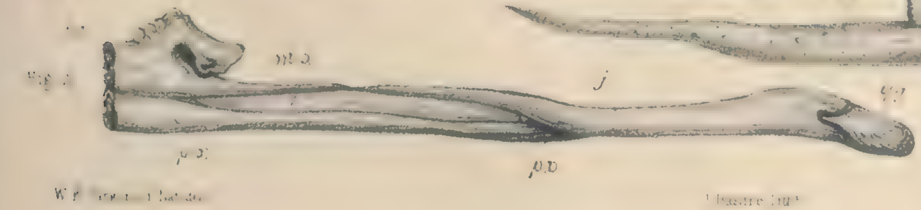
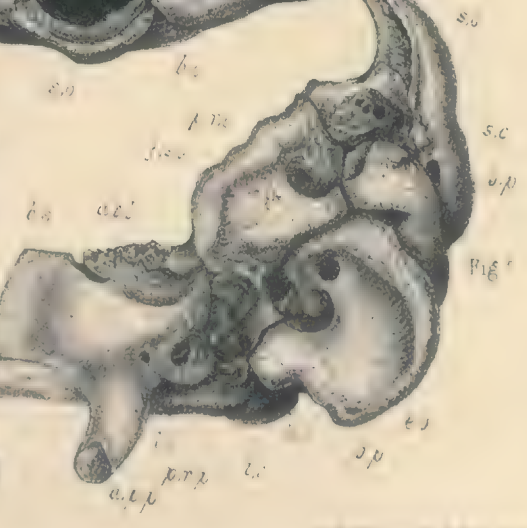


Fig 4

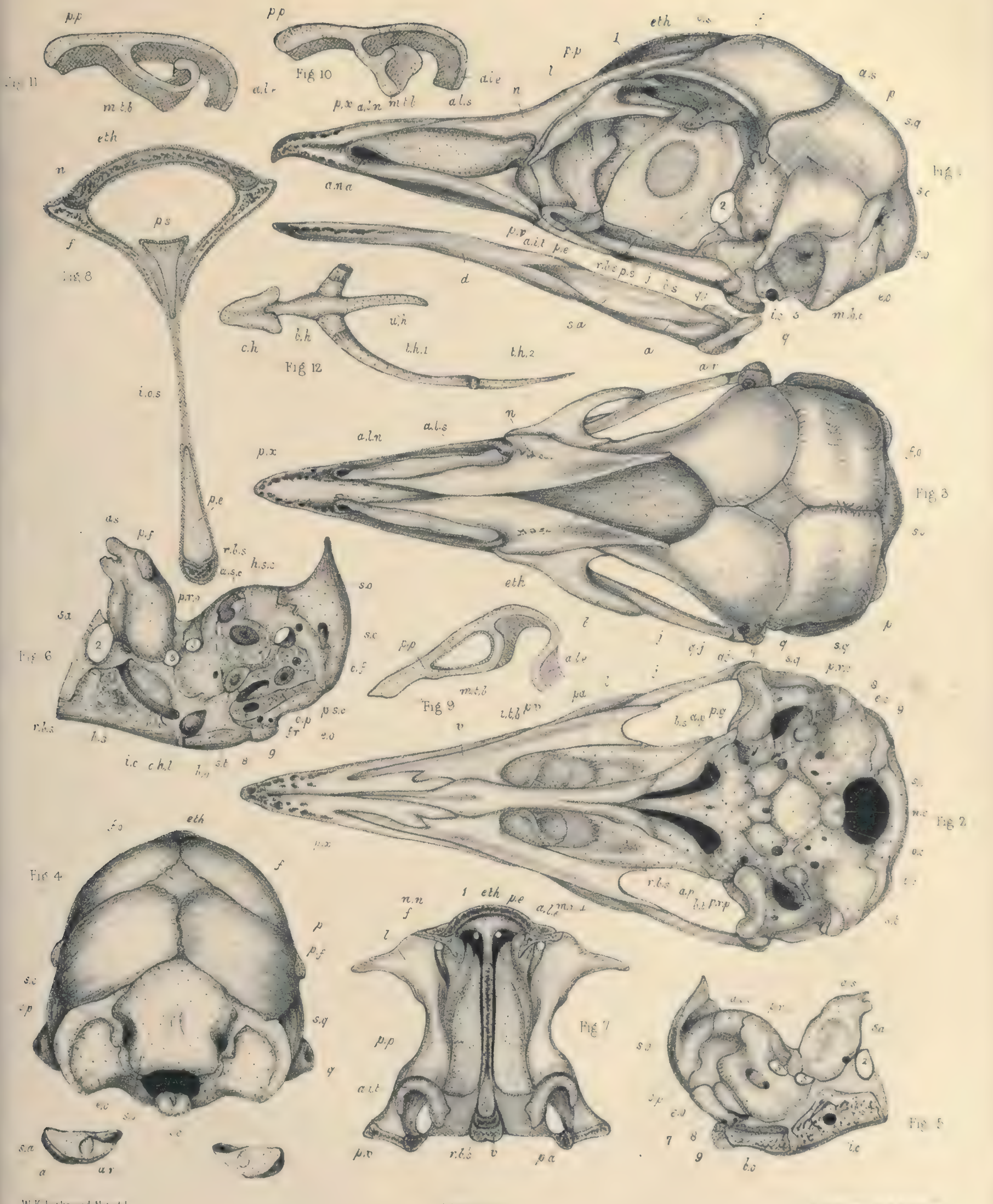


Fig

W. K. [illegible] del. ad. nat.   [illegible] lith.   [illegible]

1. [illegible] Dromaeus irroratus [illegible] 1½ Diam. 12. 13 [illegible] 4 Diam.

[illegible] Page 148, 149.



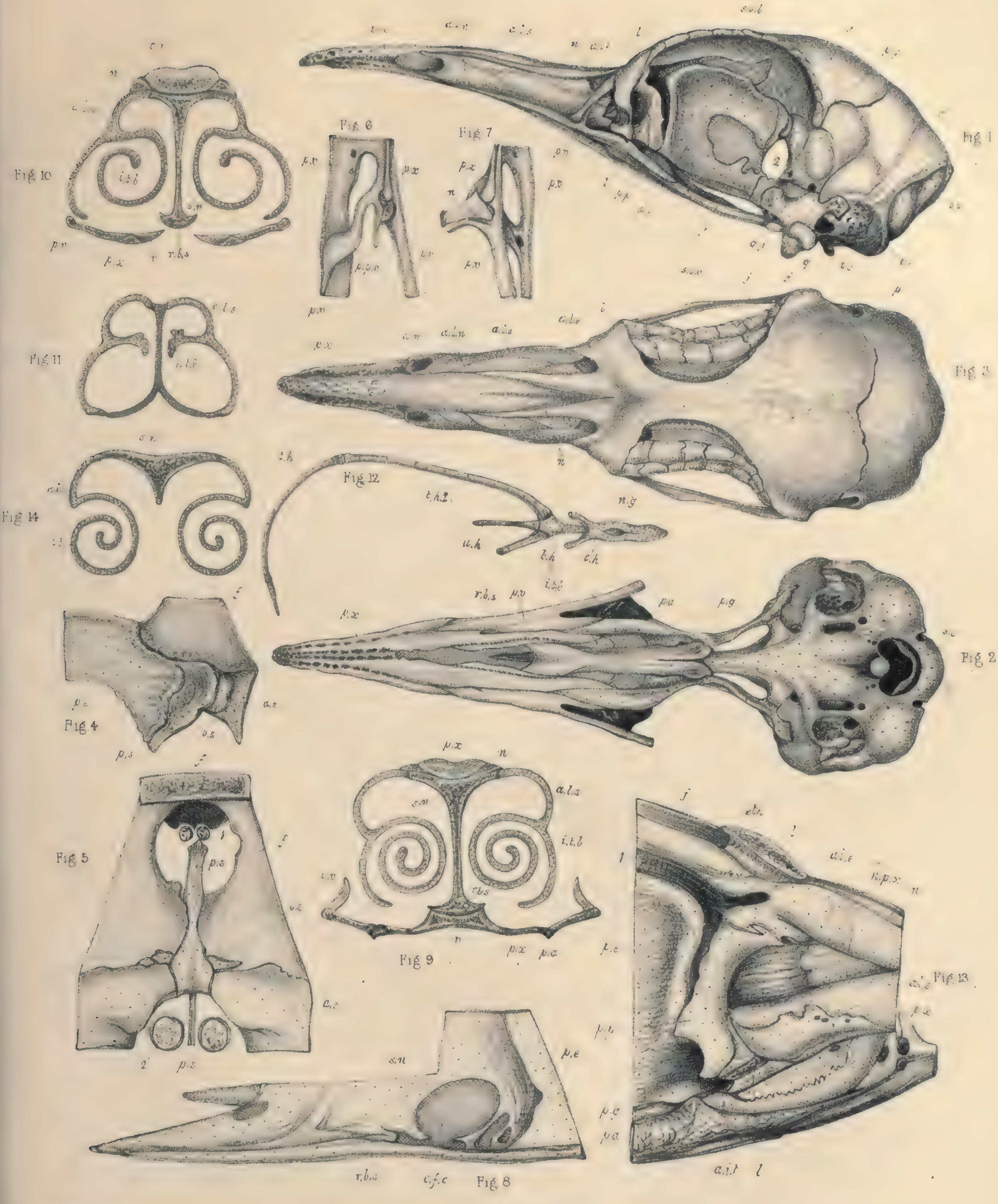
W. K. Parker ad Nat. del.

J. Basire lith.

T. M. Williams F.L.S. F.Z.S. del.

Casuarius Bennetti. 2, 4, & 5 Diam.

Pl. 14. Page 152 – 162.



W K Parker ad Nat del

J Basire lith^r

E M Williams F.L.S F.Z.S. Lith

1 2 3 & 12 Tinamus variegatus 2 Diam 4 & 9 13 T var 4 Diam 5 8 T robustus 4 Diam 14 Psophia crepitans 4 Diam

Pl 15 Page 176 – 178

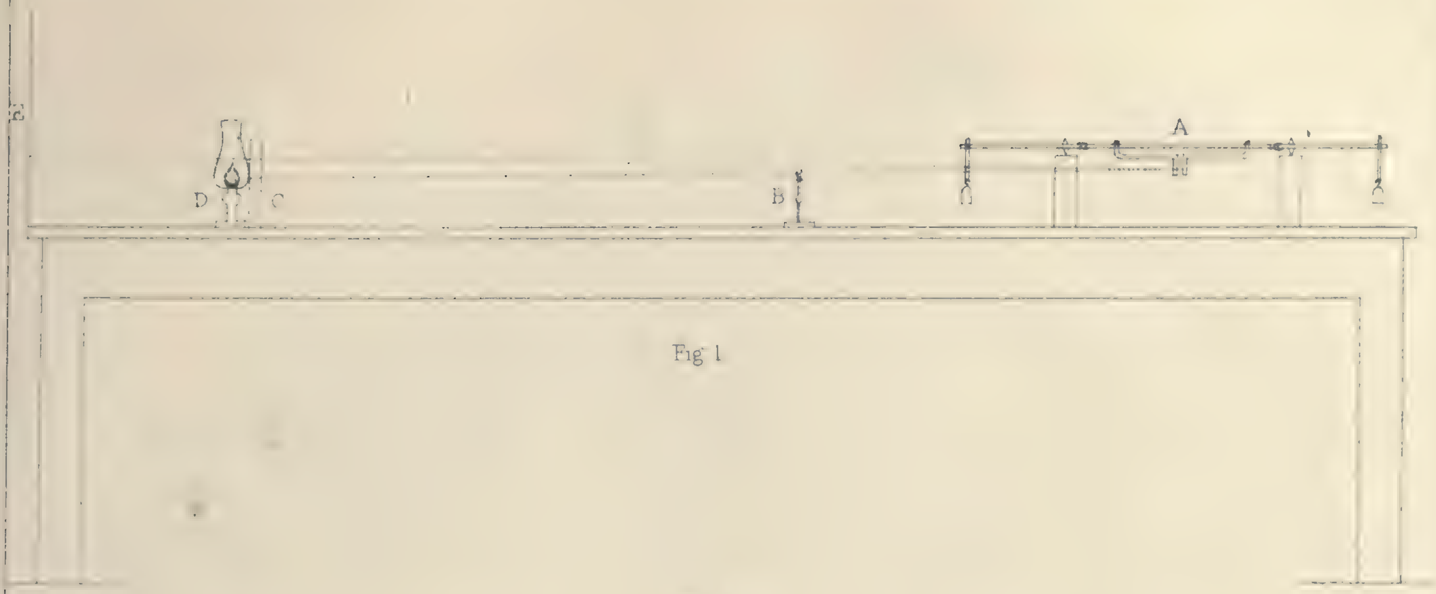
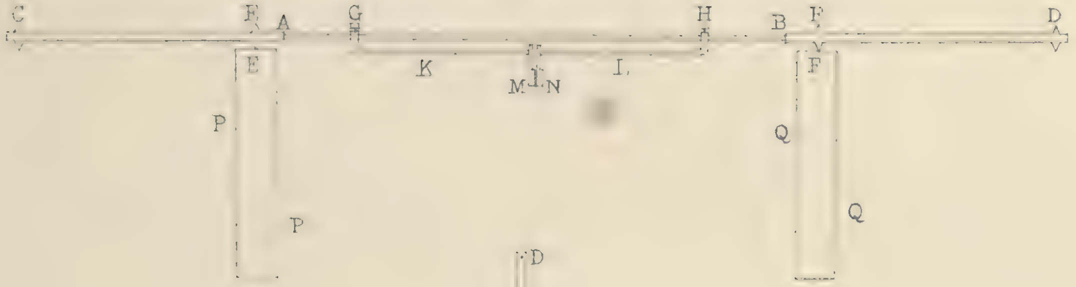


Fig. 1.

Fig. 2.



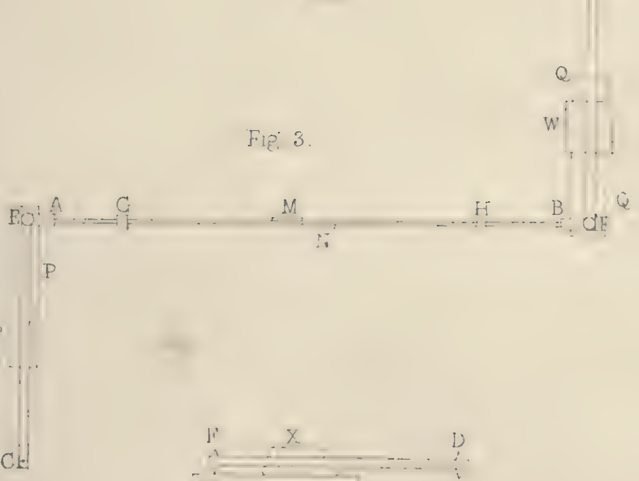
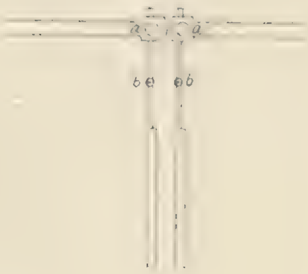


Fig. 3.

Fig. 4.



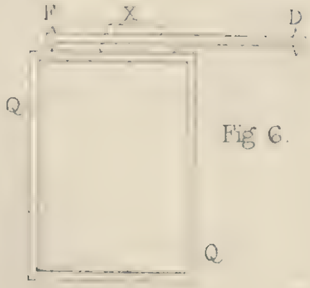


Fig. 6.

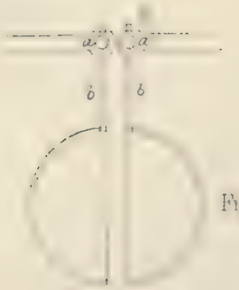


Fig. 5.

J. Basire lith.

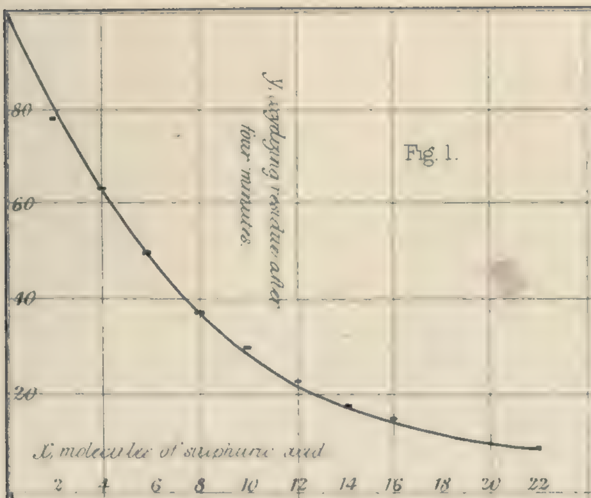


Fig. 1.

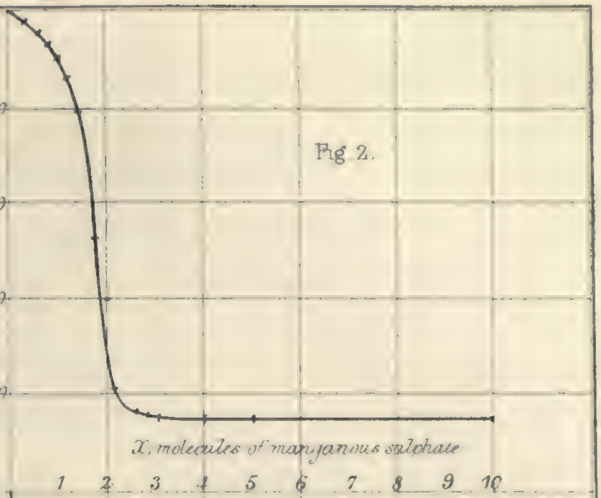


Fig. 2.

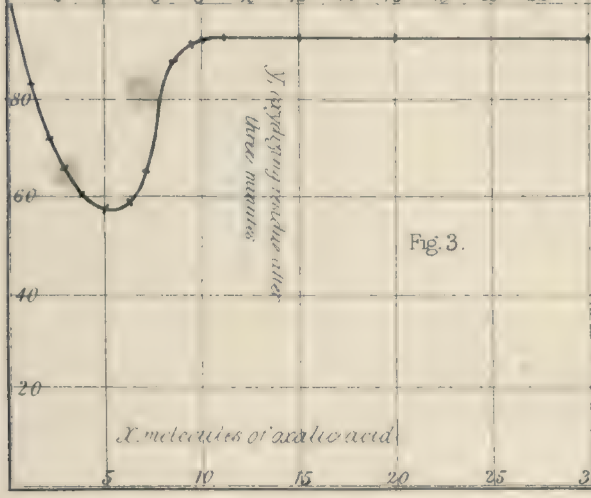


Fig. 3.

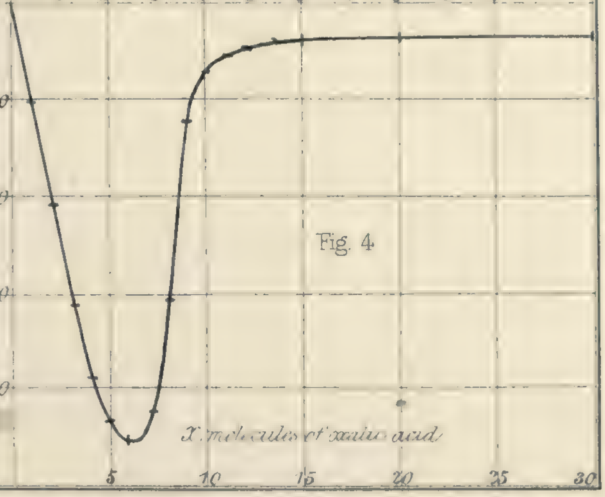


Fig. 4.

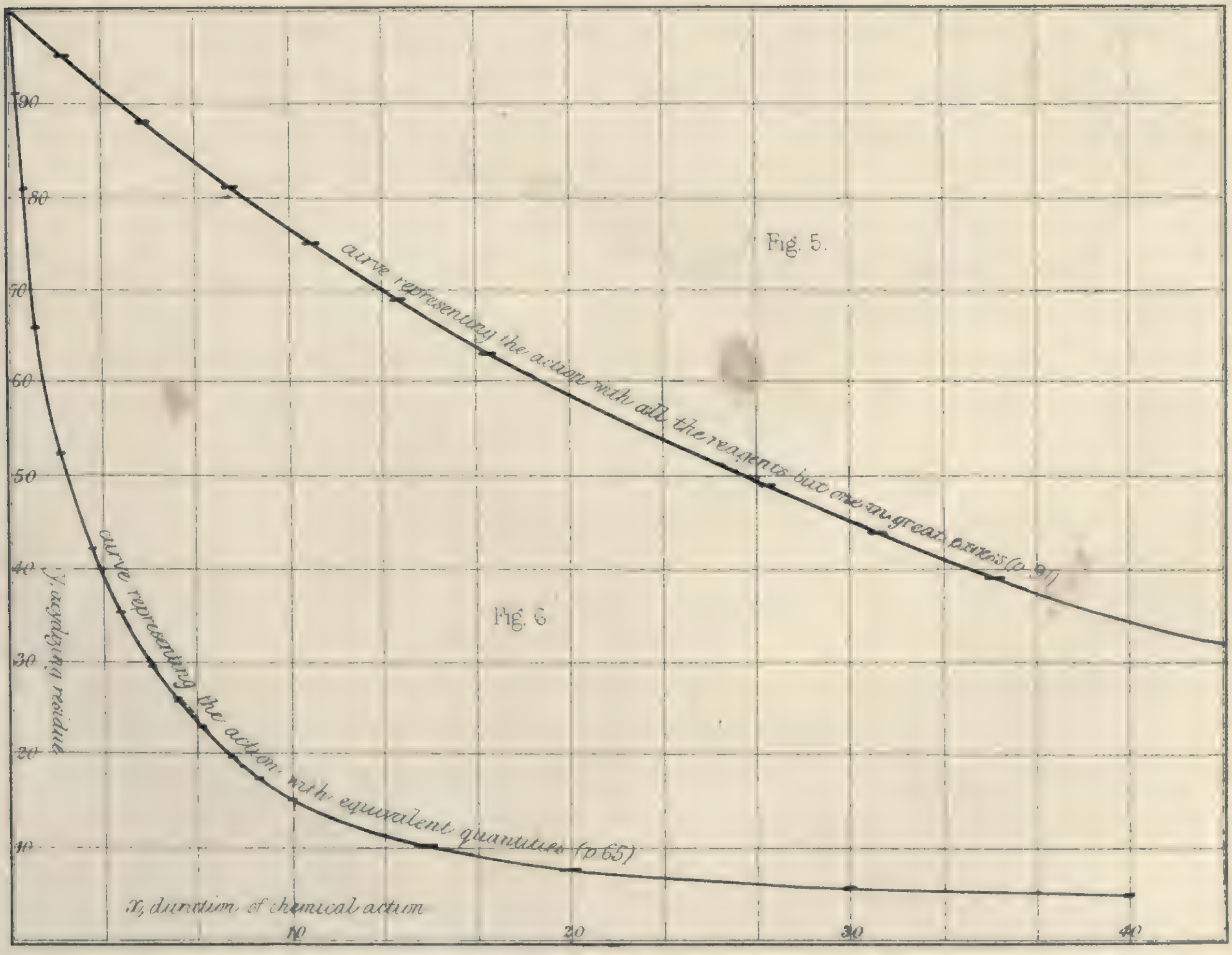


Fig. 5.

Fig. 6

J. Basire lith

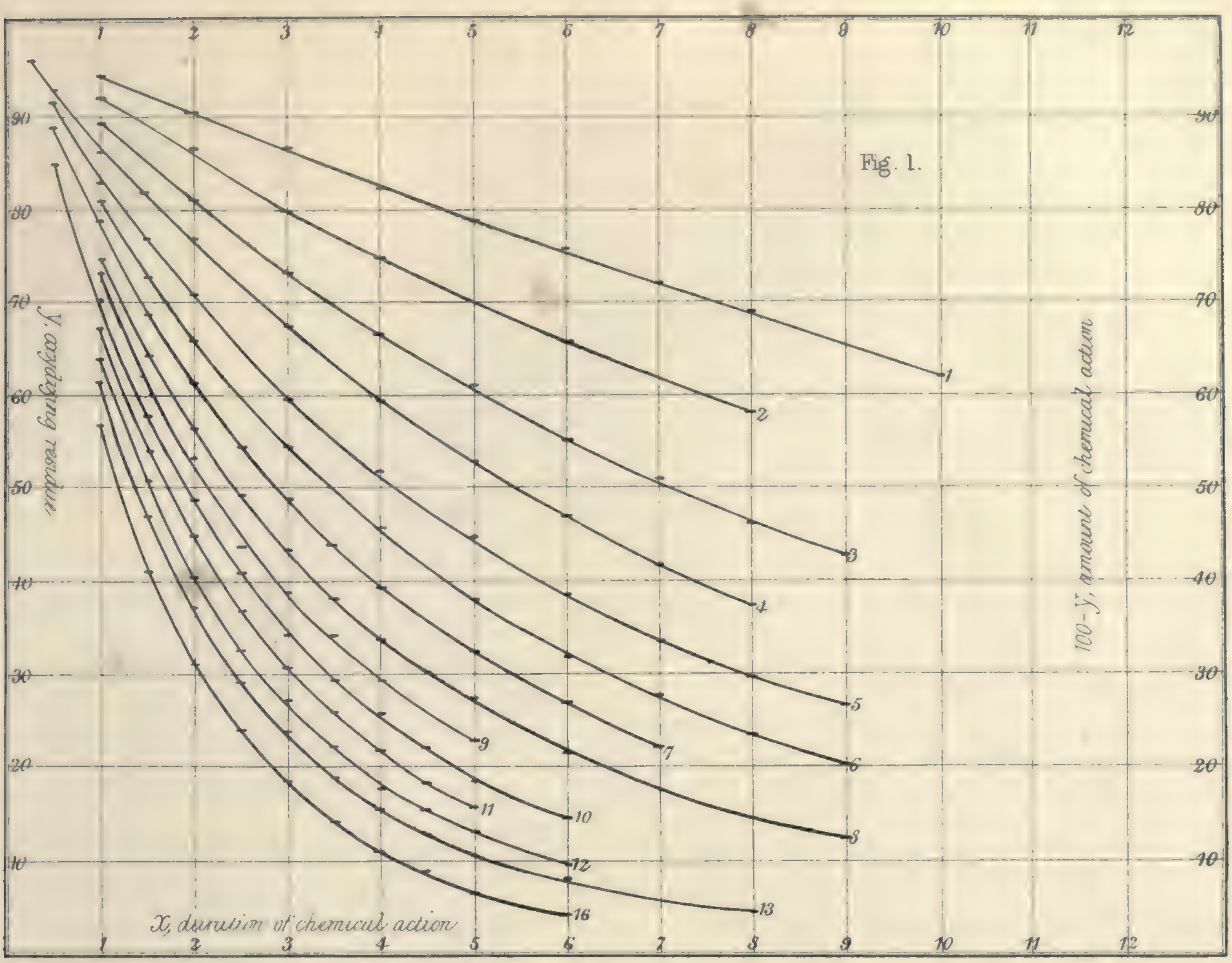


Fig. 1.

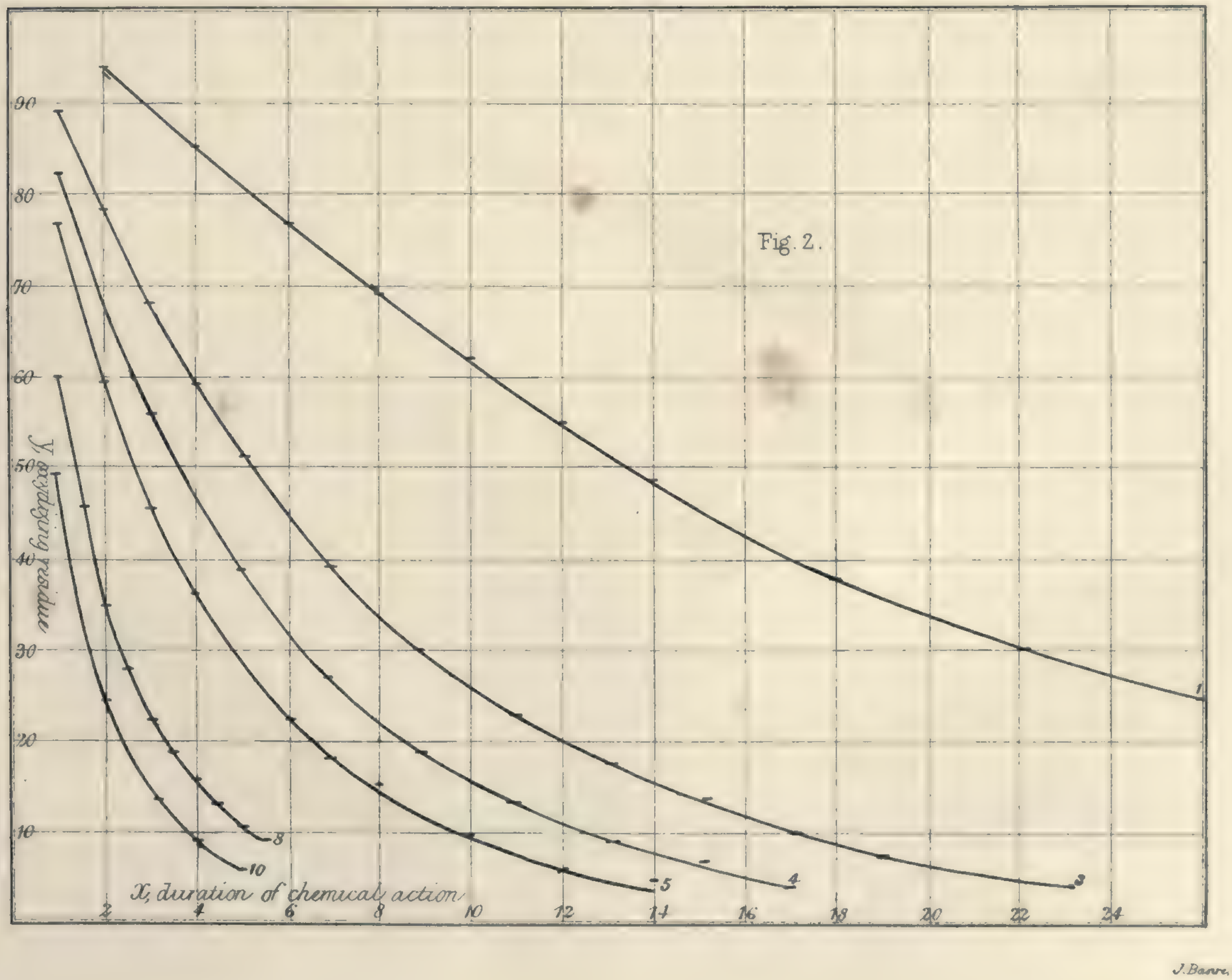


Fig. 2.

J. Basire, lith.

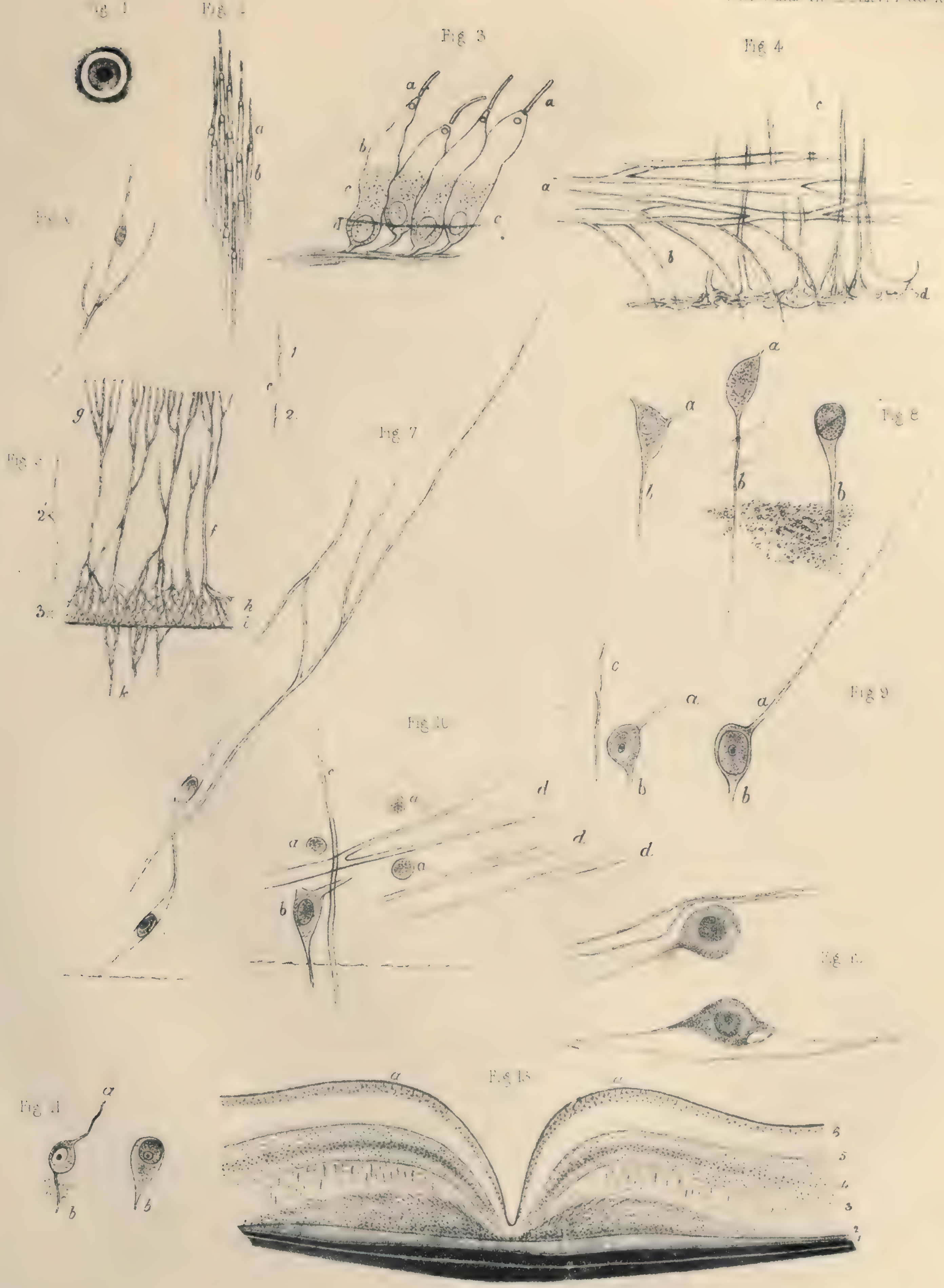


Fig. 1
Fig. 2
a
b
Fig. 3
a
a
b
c
c
d
Fig. 4
c
a
b
d
Fig. 5
Fig. 6
g
f
h
i
k
1
c
2
2
3
Fig. 7
Fig. 8
a
a
b
b
b
Fig. 9
c
a
a
b
b
Fig. 10
c
a
a
a
b
d
d
d
Fig. 12
Fig. 11
a
b
b
Fig. 13
a
a
6
5
4
3
2
1

Fig 1.

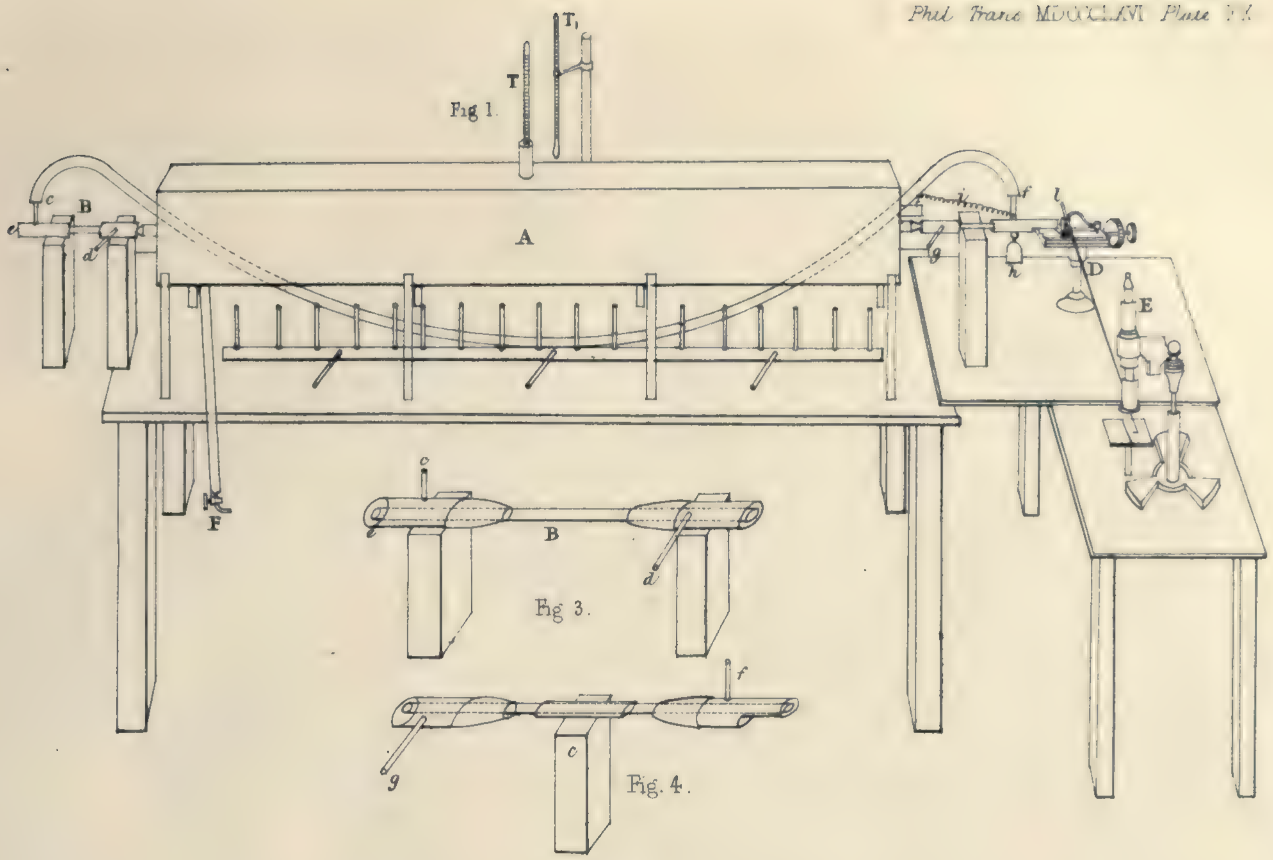
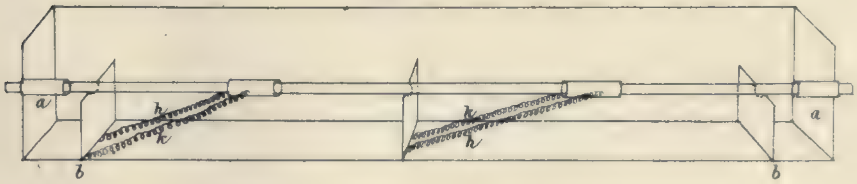


Fig 3.

Fig. 4.

Fig. 2.



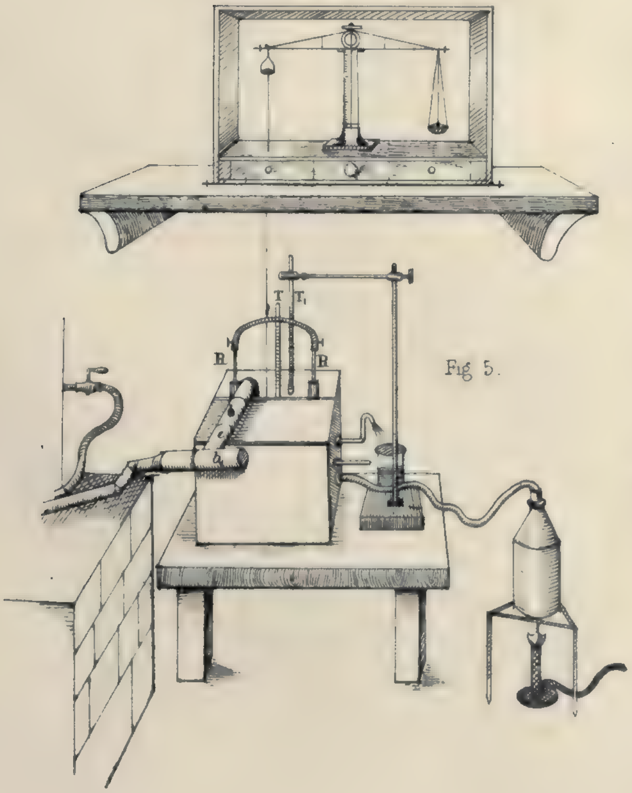
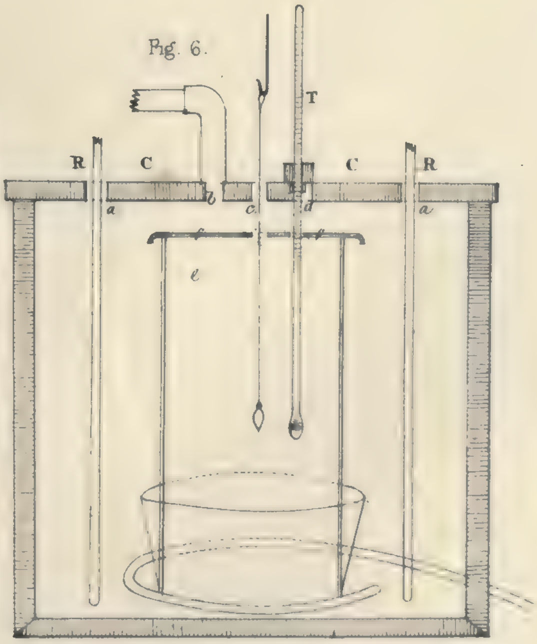


Fig 5.

Fig. 6.



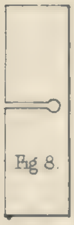
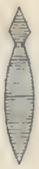


Fig 8.

Fig. 7.



J. Basire lith.

Fig. 1.

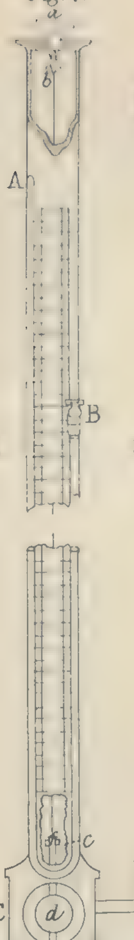


Fig. 8.

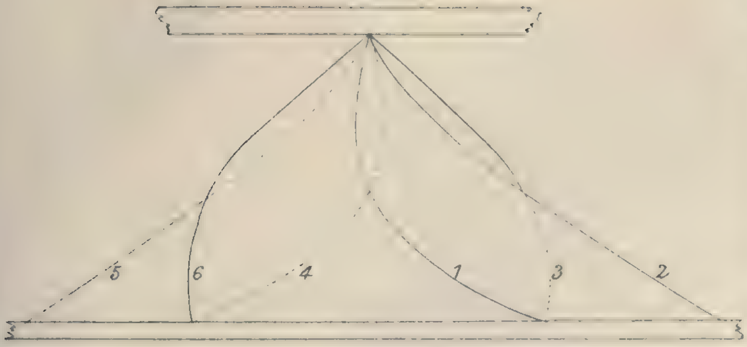


Fig. 9.

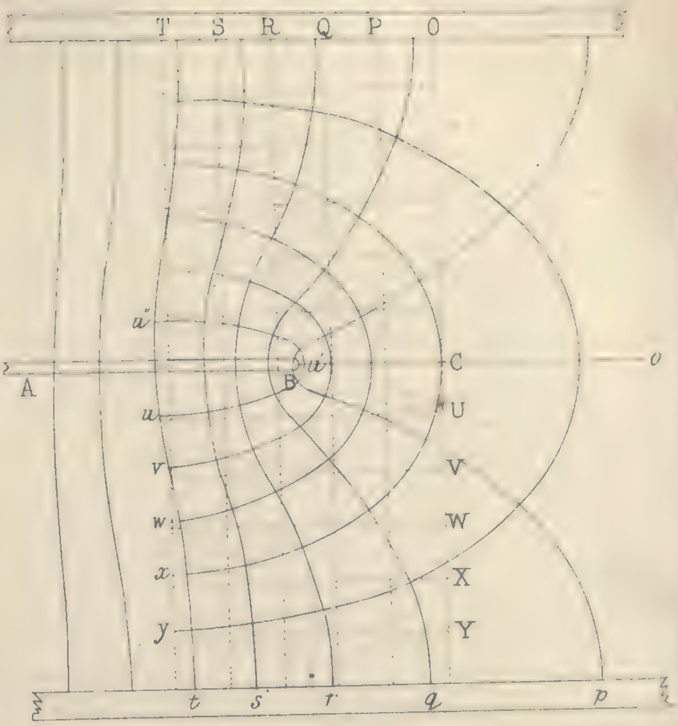


Fig. 2.

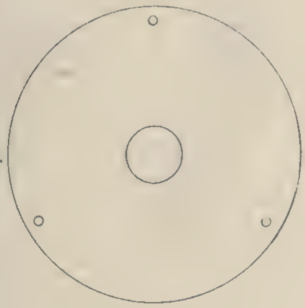


Fig. 7.

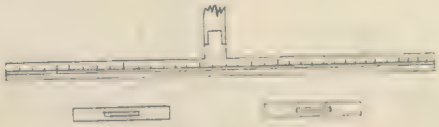


Fig. 3.

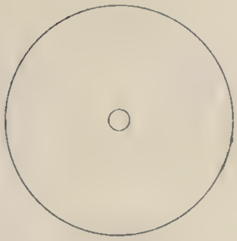


Fig. 4.

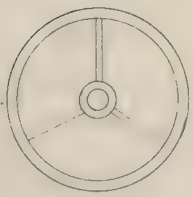


Fig. 6.

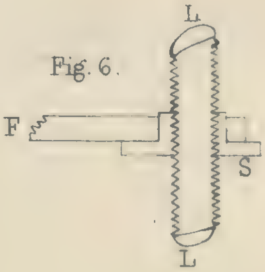


Fig. 5.

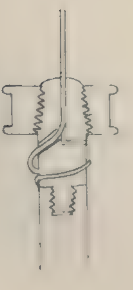
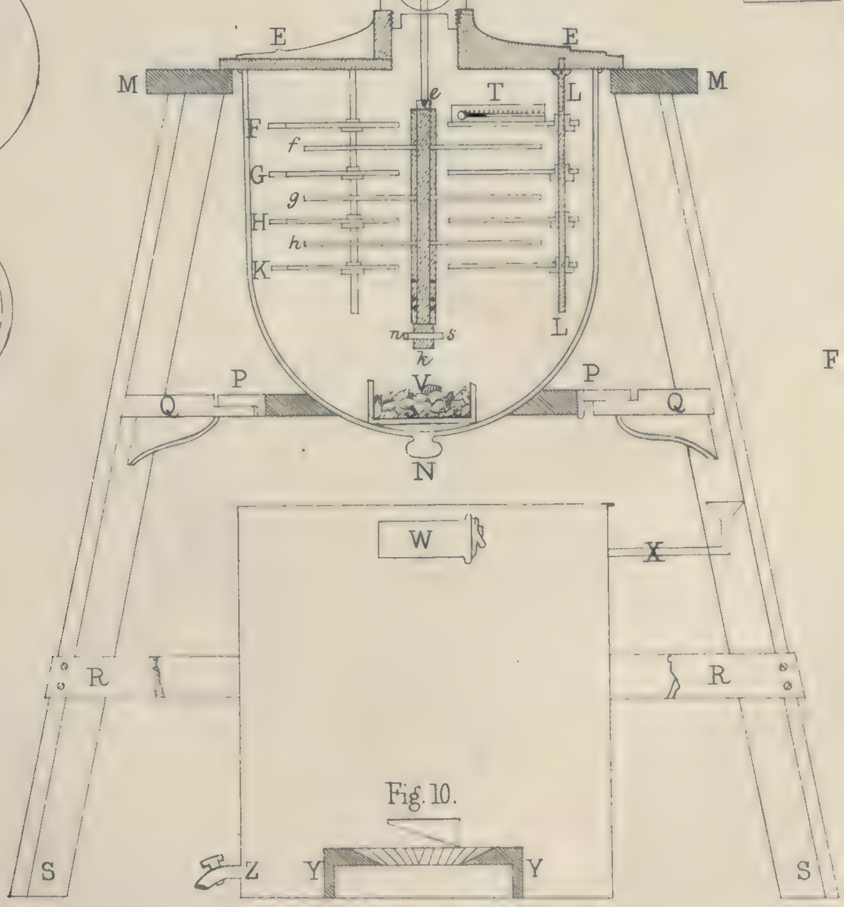


Fig. 10.



J. Basire lith.

XVIII. *On the Absorption and Dialytic Separation of Gases by Colloid Septa.*

By THOMAS GRAHAM, *F.R.S., Master of the Mint.*

Received June 20,—Read June 21, 1866.

PART I.—ACTION OF A SEPTUM OF CAOUTCHOUC.

MIXED gases must differ considerably in diffusibility and specific gravity, in order to separate from one another to any great extent in their molecular passage into a vacuum through a porous septum, such as the plate of graphite or the walls of an unglazed earthenware tube. The agency of atmolysis is therefore very limited in parting the oxygen and nitrogen of atmospheric air—gases which differ so little in density from each other.

Substances existing in the liquid condition often admit of being separated much more fully than gases, by the proper use of dialytic septa in addition to the agency of liquid diffusion.

Evidently there cannot be anything like the dialysis of gases; for dialysis involves the passage of a substance through a septum composed of soft colloid matter, such as must be wholly destitute of open channels, and therefore be impermeable to gas as such. Still liquid dialysis may be imported into the treatment of gases, in consequence of the general assumption of liquidity by gases when absorbed by actual liquids or by soft colloids. Water when charged with air holds liquid oxygen and nitrogen in solution; and the latter substances then become amenable to liquid diffusion and dialysis, and so penetrate animal membrane in the act of respiration.

A considerable time ago Dr. MITCHELL of Philadelphia discovered a power in gases to penetrate india-rubber in a thin sheet, or in the form of the little transparent balloons which Dr. MITCHELL was the first to prepare from that substance. He remarked in particular that such balloons collapse sooner when inflated with hydrogen than with atmospheric air, and still sooner when filled with carbonic acid; and he connected the latter fact with the observation that a solid piece of india-rubber is capable of absorbing its own volume of carbonic acid when left long enough in the pure gas. By means of a proper arrangement, Dr. MITCHELL found that various gases passed spontaneously through the caoutchouc membrane, *when there was air on the other side*, with different degrees of velocity. "Ammonia transmitted in 1 minute as much as sulphuretted hydrogen in $2\frac{1}{2}$ minutes, cyanogen in $3\frac{1}{4}$ minutes, carbonic acid in $5\frac{1}{2}$ minutes, nitrous oxide in $6\frac{1}{2}$ minutes, arsenietted hydrogen in $27\frac{1}{2}$ minutes, olefiant gas in 28 minutes, hydrogen in $37\frac{1}{2}$ minutes, oxygen in 1 hour and 53 minutes, carbonic oxide in 2 hours

5

and 40 minutes." The rate of penetration of nitrogen appeared to be even slower than that of carbonic oxide[*].

It will be observed that those gases penetrate most readily which are easily liquefied by pressure, and which are also "generally highly soluble in water or other liquids." The memoir of Dr. MITCHELL was ably commented upon, shortly after its publication, by Dr. DRAPER of New York, who also added many new observations on the passage of both gases and liquids through membranous septa[†]. These early speculations, however, lose much of their fitness from not taking into account the two considerations already alluded to, which appear to be essential to the full comprehension of the phenomena—namely, that gases undergo liquefaction when absorbed by liquids and such colloid substances as india-rubber, and that their transmission through liquid and colloid septa is then effected by the agency of liquid and not gaseous diffusion. Indeed the complete suspension of the gaseous function during the transit through colloid membrane cannot be kept too much in view.

Dr. MITCHELL was led to infer, from a single casual observation, that rubber expands in volume when carbonic acid is absorbed—a result tobe expected from the porosity of the solid mass, then assumed in explanation of the penetrativeness of gaseous fluids. But on placing 50 grms. of thin sheet rubber, 0·6 millim. in thickness, in carbonic acid over mercury, it was seen that the rubber gradually absorbed 0·78 volume of gas in twenty-four hours at 15°, of which 0·7 volume was taken up in the first hour. The mass of rubber was previously measured with care by the displacement of mercury in a specific-gravity bottle, and again when the rubber was charged with carbonic acid; it gave the same displacement of mercury within a hundredth of a gramme. No measurable change in the bulk of the rubber, therefore, had occurred. It may be added that the absorbent power of vulcanized rubber for carbonic acid appears to be less than that of rubber in its natural state, being found only 0·57 volume in a comparative experiment.

The penetration of rubber by gases may be illustrated by their passage into a *vacuum*, as well as into an atmosphere of another gas in Dr. MITCHELL'S experiments. The diffusiometer, consisting of a plain glass tube of about 22 millims. in diameter and nearly a whole metre in length, closed at the upper end by a thin plate of stucco and open below, is taken advantage of in such experiments. A thin film of rubber from a small balloon is stretched over the upper end of the tube, where it is supported by the stucco plate, bound with copper wire, and cemented at the edges in contact with the glass with gutta percha softened by heat. If the tube be now filled with mercury and inverted, a Torricellian vacuum is obtained above, into which the air of the atmosphere gradually penetrates, passing through the film of rubber and depressing the mercurial column in the tube. In order to compare the penetration of different gases, a hood of thick vulcanized rubber, provided with a small entrance- and exit-tube for gas (such as is often used in gas experiments), is placed over the upper end of the diffusiometer described, and cemented to it by means of fused gutta percha. The gas to be operated upon can thus be conveyed from the apparatus in which it is generated, or from a gasometer in which the gas is stored, into the hood or upper chamber of the diffusiometer, and the excess of gas supplied be allowed to escape into the atmosphere by the exit-tube of the hood. The stucco plate used as a support to the film of rubber is so highly porous as not to add sensibly to the resistance experienced by the gases in passing through the rubber, and, having no absorbent power of its own, may be left entirely out of consideration.

---

[*] "On the Penetrativeness of Fluids," by J. K. MITCHELL, M.D.—Philadelphia Journal of Medical Sciences, vol. xiii. p. 36; or Journal of the Royal Institution, vol. ii. pages 101 and 307: London, 1831.

[†] A Treatise on the forces which produce the organization of Plants, with an Appendix containing several Memoirs on Capillary Attraction, Electricity, and the Chemical Action of Light, by JOHN WILLIAM DRAPER, M.D.

A comparison was made of the passage through the rubber film, on the same day, of carbonic acid, hydrogen, oxygen, and nitrogen; barom. 773 millims., therm. 23° to 23°·5 C. The time during which the mercurial column fell in the diffusiometer from 748 to 723 millims. was noted in seconds, and also from 723 to 698 millims. The gases were all carefully dried.

TABLE I.—Passage of Carbonic Acid in seconds.

Height of mercurial column in diffusiometer.	Experiment 1.	Experiment 2.	Experiment 3.
millims.			
748			
723	107″	102″	102″
698	143	138	138
	250	240	240

The passage of carbonic acid thus exhibited will be found to be considerably more rapid than those of hydrogen and the two other gases which follow:—

TABLE II.

Height of mercurial column in diffusiometer.	Passage in seconds, of Hydrogen.		of Oxygen.		of Nitrogen.	
	Experiment 1.	Experiment 2.	Experiment 1.	Experiment 2.	Experiment 1.	Experiment 2.
millims.						
748						
723	277″	270″	545″	554″	1413″	1428″
698	316	323	727	722	1832	1850
	593	593	1272	1276	3245	3278

A single experiment, made at the same time on the passage of atmospheric air, gave times of 1318″ and 1524″ for the two stages, or 2842″ for the whole fall. The time of penetration of air is therefore intermediate between that of oxygen and nitrogen entering singly.

Although such numbers do not possess the close uniformity which appears in diffusion-

and transpiration-experiments, for reasons which will immediately appear, yet they give a comparative estimate of the penetrativeness of the different gases through rubber, which may be available for some practical purposes.

Upon another occasion carbonic oxide and marsh-gas (CH_4) were introduced into the comparison, the same film of rubber remaining upon the diffusiometer; barom. 768 millims., therm. 19°·5 C.

TABLE III.

Height of mercurial column in diffusiometer.	Passage in seconds,								
	of Carbonic oxide.		of Hydrogen.		of Carbonic acid.			of Marsh-gas (CH_4).	
	Expt. 1.	Expt. 2.	Expt. 1.	Expt. 2.	Expt. 1.	Expt. 2.	Expt. 3.	Expt. 1.	Expt. 2.
millims. 748									
723	1620″	1631″	435″	434″	125″	119″	117″	803″	821″
698	1920	1924	505	511	170	169	172	1009	1045
	3540	3555	940	945	295	288	289	1812	1866

The results may be summed up by deducing the times in which a constant volume of the various gases is transmitted by the rubber, the time of passage of carbonic acid, which is the shortest, being taken as unity for the sake of comparison.

Penetration of rubber by equal volumes of Gas.

	Time.
Carbonic acid	1
Hydrogen	2·470
Oxygen	5·316
Marsh-gas (CH_4)	6·326
Atmospheric air	11·850
Carbonic oxide	12·203
Nitrogen	13·585

Or, with the times taken equal, the volume of each gas which passes then expresses the velocity of penetration.

Penetration of rubber in equal times.

	Velocity.
Nitrogen	1
Carbonic oxide	1·113
Atmospheric air	1·149
Marsh-gas (CH_4)	2·148
Oxygen	2·556
Hydrogen	5·500
Carbonic acid	13·585

Considering the circumstances in which the gases pass through the sheet of rubber into a vacuum, it is not to be expected that any relation will be found among the preceding numbers, as between the coefficients of diffusion in gases. The first absorption of the gas by rubber must depend upon a kind of chemical affinity subsisting between the material of the gas and substance of rubber, analogous to that attraction which is admitted to exist between a soluble body and its solvent, conducing to solution. Carbonic acid being soluble in ether and volatile oils, it is not wonderful that it is also dissolved by the hydrocarbons of rubber. The rubber being *wetted through* by the liquefied gas, the latter comes to evaporate into the vacuum, and reappears as gas on the other side of the membrane. Now it is known that such evaporation is the same into a vacuum and into another gas, being equally gas-diffusion in both circumstances. It is not indispensable, therefore, to have a vacuum on one side of the rubber membrane as in the experiments detailed above. A foreign gas will answer for the vacuum, as in the experiments of Dr. MITCHELL.

The numbers for the velocity of passage of the different gases in the last Table may be taken also as representing not remotely the relative absorption and liquefaction of the various gases by the substance of rubber.

The passage of gases through rubber is also illustrated by the rapid collapse of the little balloon when filled with carbonic acid gas, or even with hydrogen, or with marsh-gas, as compared with atmospheric air. The converse fact is observed when the inflating gas is pure nitrogen: then the balloon is found to become further distended after a few hours, in consequence of more oxygen entering from the atmosphere without, than of nitrogen escaping from the balloon during the same time; while the composition is being equalized on both sides of the membrane, and the gas within the balloon is finally of the same composition as the external air. A rubber balloon filled with nitrogen was found, when roughly gauged, to increase in diameter from 132 to 136 millims. in the course of twenty-four hours. On the other hand, a balloon filled with pure oxygen fell in the same time from 150 to 113 millims. in diameter.

In forty-eight hours a balloon filled with hydrogen 154 millims. in diameter contracted to 87 millims., and then contained 250 cub. centims. gas, of which 53 cub. centims. were absorbed by pyrogallic acid and potash, showing the presence of 21·2 per cent. of oxygen, or sensibly the same proportion as in the external atmosphere.

If the upper end of a diffusiometer be closed by a thin sheet of rubber, and the instrument standing over mercury be filled with hydrogen gas, a contraction is observed to take place slowly, but to a greater extent ultimately than could be due to the diffusion of hydrogen as a gas. Beginning with 249 volume divisions of gas in the tube, the rise of the mercurial column, or reduction of volume, was 1·5 division in the first hour, 1·5 division in the second hour, 2·0 in the third hour, 3 in the fourth hour, and 51 divisions in the first twenty-four hours taken together. Then the rise in the following successive days was 42, 59, 37, 29, 13, 5, 1, 0·5, 0·5 (in two days), and 0·0, the original volume of 249 volumes of hydrogen being finally replaced by 53 volumes of atmospheric air; barom.

747 millims., therm. 21°·1. The ultimate replacing volumes are here as 1 to 4·7. In gas-diffusion they are as 1 to 3·8.

A balloon filled with air subsided in forty-eight hours from 150 to 147 millims. in diameter, from the mechanical effect alone of the elasticity of the membrane in compressing the enclosed gas. These little balloons vary from 0·75 to 1 grm. in weight. Supposing the form to be truly spherical, a balloon of 150 millims. in diameter would have a surface of 0·0706 square metre (5·905 inches in diameter and 0·08454 square yard of surface). Supposing the balloon to be 1 grm. in weight, the thickness of the membrane will be $\frac{1}{70·686}$ of a millim., with a specific gravity =1, or $\frac{1}{76·01}$ of a millim., with a specific gravity =0·93, the admitted density of pure rubber. This last is a thickness of $\frac{1}{1930·6}$ of an inch, or it would require nearly 2000 such films, laid upon each other, to form the thickness of a single inch. Yet such a film of rubber appears to have no porosity, and to resemble a film of liquid in its relation to gases—differing entirely in this respect from a thin sheet of paper, graphite, earthenware, or even gutta percha, as will appear hereafter. These last enumerated bodies appear all to be pervaded by open channels or pores, sufficiently wide to allow gases to be projected through by their own proper molecular movement of diffusion. But liquids and colloids have an unbroken texture, and afford no opportunity for gaseous diffusion. They form even in the thinnest film an impervious barrier to gas.

The penetration of rubber is much affected by temperature, and apparently in two different ways at the same time. An increase of temperature no doubt renders all gases less easily liquefied by pressure, and consequently less considerably absorbed by any liquid or colloid. But such an influence of heat appears to be counteracted in rubber by the tendency of that colloid to become more soft when heated, and to acquire more of liquid and less of solid properties. Certainly the rubber film becomes more and more permeable to gases as the temperature is elevated, within a moderate range. This was distinctly observed in operating with silk cloth varnished on one side with rubber, such as is sold as a waterproof material. Without anticipating a detail of the experiments, it may be stated in general terms that the same specimen of rubber was penetrated by air from the atmosphere passing into a vacuum, at the following rates per square metre of surface:—

At 4° C., by 0·56 cub. centim. of air in 1 minute.
At 14° C., by 2·25 ,, ,, ,,
At 60° C., by 6·63 ,, ,, ,,

The volumes of gas are all reduced to barom. 760 millims. and therm. 20° C.

Such numbers are probably not strictly constant; for it appears that the effect of temperature upon rubber is much influenced by the length of time that the temperature is continued, the change in degree of softness with change of temperature requiring hours, or even days, fully to complete it. The rigidity of rubber under cold and its softening under warmth are well known to take place in a slow and gradual manner.

With the softening of rubber by heat, the *retentive* power of that substance for gases appears to be modified. Soft rubber, first charged with carbonic acid at 20°, and then made rigid by cold, appeared to lose its carbonic acid, when afterwards freely exposed to air, less rapidly than the same rubber equally charged but exposed from the first in its soft condition. The quantity of carbonic acid retained in the former case was 10·76 per cent., and in the latter 7·08 per cent. of the volume of the rubber, after a similar exposure of forty-eight hours. This point, although not sufficiently examined, is alluded to here on account of the analogy which appears to hold between rubber and the malleable metals in a power to absorb a gas when they are softened by heat, and to retain the same gas with great tenacity when they are afterwards made rigid by cold.

The condensation of oxygen gas by masses of solid rubber punched out of a block was made the subject of observation, by placing 50 grms. of that substance within a jar of oxygen standing over mercury during a period of several days. From the rubber afterwards there was extracted, by the action of a vacuum continued for twenty-one hours, 6·21 cub. centims. of gas; of which 3·67 cub. centims. were oxygen, 0·14 carbonic acid, and the remainder chiefly nitrogen. Taking the bulk of the rubber at 53·8 cub. centims., the oxygen absorbed amounts to 6·82 per cent. of the volume of the rubber. Oxygen then may be regarded as fully twice as soluble in rubber as the same gas is in water at the ordinary temperature. No experiment was made at a higher temperature; but as the penetrativeness of rubber is much increased by heat, the presumption is that the solubility of gases in rubber is increased in the same degree.

More than one attempt was made to identify the presence of free hydrogen in the substance of rubber after being kept in that gas for some time, but with a negative result. The absorbed hydrogen may be too easily dissipated, owing to its extreme volatility.

Dialytic separation of Oxygen from Atmospheric Air, (1) *by means of other gases,* (2) *by means of a vacuum.*

1. A balloon of rubber filled with *hydrogen* and exposed to the atmosphere, gradually loses the former gas, which is finally replaced by a considerably smaller volume of air, presenting a deceptive resemblance to the diffusion of hydrogen gas into air. When the progress of the entrance of air was observed at different stages of the exchange, it appeared that after three hours, when the balloon had fallen from 150 to 128 millims. in diameter, the composition of its contents was—

Oxygen . .	8·98	41·6
Nitrogen . .	12·60	58·4
Hydrogen . .	78·42	
	100·00	100·0

Setting aside therefore the hydrogen still remaining, the balloon now contained a portion of a mixture of oxygen and nitrogen in the proportion of 41·6 volumes of the former to 58·4 volumes of the latter. This was the largest proportion of oxygen to the nitrogen observed; for the former gas has a tendency to flow back again to the external atmosphere when the hydrogen becomes small in volume; and the proportion of oxygen becomes eventually no higher than 21 per cent. of the whole gases remaining in the balloon, including the hydrogen. Thus after six hours the proportion of oxygen was 33·63 to nitrogen 66·37 volumes, and after twenty-four hours oxygen 26·48 to nitrogen 73·52 volumes, the hydrogen constantly diminishing at the same time.

The entrance by infiltration of atmospheric air into a balloon of rubber inflated with *carbonic acid* gas brings us still nearer to a practical dialytic separation, as the carbonic acid can be withdrawn entirely by means of caustic alkali, after a certain time has elapsed, and the infiltered air enriched with oxygen be dealt with by itself. A balloon containing carbonic acid, when placed in the atmosphere, was reduced in four hours from 160 to 90 millims. in diameter, and it had now acquired 199 cub. centims. of gas not dissolved by alkali. This gas was capable of reviving the combustion of wood burning without flame, and was found to consist of

Oxygen	37·1 vols.
Nitrogen	62·9 „
	100·0

To produce this concentration of oxygen, it is quite necessary that the operation be interrupted at an early stage, as was done in the last experiment; otherwise the oxygen diminishes again in proportion to the nitrogen, falling at last to the normal proportion of 21 per cent. as in the external air. Thus a balloon inflated by carbonic acid to 150 millims. in diameter, was found to lose nearly all its carbonic acid in the course of twenty-four hours. It gave 150 cub. centims. of gas after treatment with caustic potash. This was air of the composition,

Oxygen	22·6
Nitrogen	77·4
	100·0

and exhibited therefore no material augmentation in the proportion of oxygen.

It may be inferred, from the familiar fact that air dissolved in water contains so high a proportion as 30 per cent. of oxygen, that if carbonic acid gas were divided from atmospheric air by a film of *water*, the former gas would come to be charged through the film with air bearing the same high proportion of 30 per cent. of oxygen. But it is not easy to imitate this experiment unless the dividing film is supported by a membrane of some sort. The air from the atmosphere, which entered a fresh ox-bladder preserved humid and inflated with carbonic acid, was found to possess 24·65 per cent. of oxygen to 75·35 of nitrogen, which is but a small increase in the proportion of oxygen. But the thickness of the membrane here was too great, and other circumstances of the experiment were unfavourable.

A balloon of rubber inflated to 150 millims. in diameter with carbonic acid was submerged in water, at 22° C., for forty-eight hours. Only a small portion of carbonic acid remained in the residual gas, which, after being washed with potash, consisted of

Oxygen	25·77
Nitrogen	74·23
	100·00

2. With the colloid septum properly supported, as by a stucco plate in the diffusiometer covered by a film of rubber (p. 400), a considerable separation of mixed gases can be effected. The constituents of atmospheric air appear to be carried through a film of rubber into a vacuum, nearly in the same relative proportion as the same gases penetrate singly (p. 402). The velocities of nitrogen and oxygen passing separately were observed to be as 1 to 2·556, and hence by calculation,

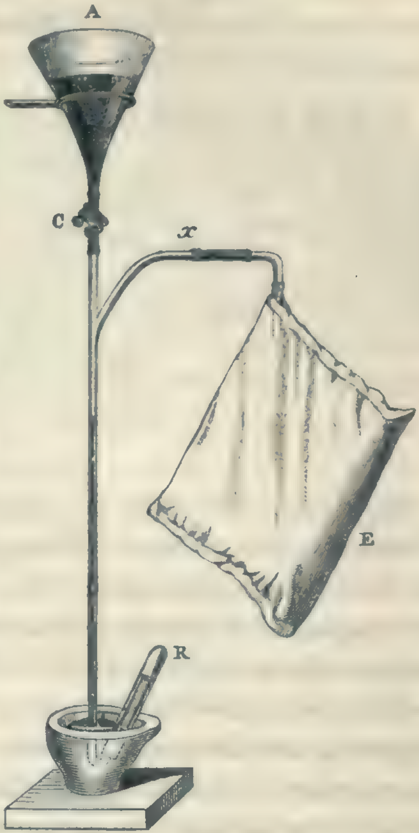
Oxygen	$21\times2·556=53·676$ . .	40·46
Nitrogen	$79\times1 \quad =79$ . .	59·54
		100·00

Hence air dialyzed by the rubber septum should consist of 40·46 oxygen and 59·54 nitrogen in 100 volumes. Now air from the atmosphere was found to enter the vacuum of the 48-inch diffusiometer-tube, through a disk of rubber 22 millims. in diameter, to the amount of 3·48 cub. centims. in twenty-one hours, under the pressure of the atmosphere; therm. 23° to 24° C. Of the 3·48 cub. centims. of gas so collected, 2 cub. centims. were absorbed by pyrogallic acid and potash, representing 42·53 *per cent. of oxygen* in the dialyzed air. Here the gas was transferred from the diffusiometer for examination by depressing the diffusiometer in mercury, and using a very narrow tube of rubber as a gas-siphon communicating between the gas in the diffusiometer and a jar inverted in the mercurial trough. The elastic tube is first filled with mercury, and, being of considerable length, a portion of it is drawn repeatedly through the fingers so as to throw the mercury and aspirated gas into the collecting receiver. The transference of gases in such circumstances may also be effected with much advantage by means of the vacuum-tube invented by Dr. Hermann Sprengel, as will immediately be shown.

The process of dialytic separation by means of a rubber septum may be varied in three points,—(1) in the condition of the rubber septum, which may be a film of rubber formed from caoutchouc varnish as well as from distended sheet rubber; (2) in the nature of the support given to the septum, which may be a backing of cotton cloth or of silk (common waterproof cloth prepared by means of caoutchouc varnish, in short), as well as a plate of stucco, earthenware, or wood; and (3) in the means had recourse to for sustaining a vacuum, or at least a considerable degree of exhaustion, on one side of the dialytic septum, while atmospheric air, or any other gaseous mixture to be dialyzed, has access to the other side of the same septum. Or the air to be dialyzed may be compressed on one side of the septum, and left of the usual tension on the other side, inequality of tension on the two sides of the septum being all that is required to induce penetration.

The pneumatic instrument of Dr. **Sprengel** (fig. 1) is peculiarly applicable to researches of the present kind. Indeed without the use of his invention some parts of the inquiry would have been practically impossible*. The instrument was originally offered by the inventor as the means of producing a vacuum, or as an air-pump. But by bending the lower end of the straight fall-tube, the instrument may be further made to deliver gas into a receiver, and be used with advantage as the means of transferring small volumes of gas from one vessel to another.

Fig. 1.



While the mercury in the funnel A is allowed to flow downward into the barometer-tube CB, of $2\frac{1}{2}$ millims. in diameter, by relaxing the clamp upon the adapter tube of rubber at C, a connexion is also made with the close receiver to be exhausted, such as an air-tight bag E, by means of the branch tube x. The air in E, gaining access to the Torricellian vacuum, is swept on by the falling mercury, and delivered below into the small gas-receiver R, previously filled with mercury and inverted over mercury in the mortar B below. The principal difficulty in obtaining a good vacuum in E by means of this apparatus arises from the necessity of joining the glass tubes in more than one place by means of adapter tubes of rubber. The directions given by Dr. **Sprengel** on this point require to be closely followed:—"The connexions between the glass tubes are made of well-fitting black vulcanized caoutchouc tubing, sold under the name of French tubing. This is free from metallic oxides, which render the tubing porous. Besides this all these joints are bound with coils of copper wire, which is easily accomplished with a pair of pliers." The joints should also be coated with gutta percha liquefied by heat, or with fused rubber. An exhausting-syringe, or air-pump, may often be used with advantage to begin the exhaustion, and to withdraw the greater bulk of the air, if the receiver is large, the Sprengel tube being reserved to complete the exhaustion. The vacuum appears to be as perfect as can be formed in a barometer-tube filled with unboiled mercury, and to come within 1 millim. of the barometric gauge.

The following modifications of the experiment exhibit the dialytic action of caoutchouc in its various forms.

---

* Researches on the Vacuum, by **Hermann Sprengel**, Ph.D., Chemical Society's Journal, ser. 2, vol. iii. p. 9 (January 1865).

1. *India-rubber between double cotton cloth vulcanized.*

This was a common elastic carriage-bag 18 inches by 15. The surface of both sides amounted to 0·3482 square metre. The bag was pressed flat by the hands, and still further exhausted by means of SPRENGEL'S tube. After all the contents of the bag were extracted and the collapse complete, the Sprengel tube began again to throw out air in a slow but exceedingly regular manner. A small portion of sawdust, or of sand, introduced beforehand into the bag, appeared to be useful in preventing the sides coming together too closely, but was not essential. The air thus extracted from the bag in one hour amounted to 15·65 cub. centims., or sensibly 1 cubic inch; therm. 23° to 24° C. Such dialyzed air, from three successive experiments of one hour each, contained 38, 40·3, and 41·2 per cent. of oxygen, the inferior proportion of oxygen in the earlier experiments being no doubt due to a small residue of undialyzed air remaining in the bag before exhaustion. This dialyzed air rekindled glowing wood, so as to illustrate the direct separation of oxygen gas from atmospheric air. For the purposes of combustion, it may be viewed as air from which one-half of the inert nitrogen has been withdrawn.

It will be convenient to express the permeability of the colloid septum with uniform reference to a square metre of area, and to an hour, or to a single minute of time. Here, for a square metre of cloth, the passage of air amounted to 44·95 cub. centims. (3 cubic inches nearly) per hour, or to 0·749 cub. centim. per minute.

The view which the observation suggests of the nature of such an air-tight fabric is, that it may be truly impenetrable to air when the composition and tension of the air are the same on both sides of the cloth; but it is penetrable when a vacuum or a reduced state of tension is maintained on one side of the cloth and not on the other. The compression of the air confined in a bag would no doubt have a similar effect, and then the flow would be in an outward direction. But there is no evidence of a porous structure in the varnished cloth. The gases of atmospheric air would pass through actual openings according to the law of gaseous diffusion, which favours the nitrogen or lighter gas, while it is the oxygen which is found to pass through the material most readily in these experiments. The imbibition of the liquefied gas by the substance of the rubber, with the subsequent evaporation of this liquid into the vacuum on the other side, is all the explanatiou required.

2. *Vulcanized india-rubber tubing.*

A stout caoutchouc tube with an external diameter of 13 millims. (half an inch), an internal diameter of 9 millims., thickness of 2 millims., and length of 3·658 metres (4 yards) was exhausted, one end being closed and the other end connected with the Sprengel pump. The gas collected in thirteen hours amounted to 11·25 cub. centims.; therm. 20° to 23° C. This gas contained 37·8 per cent. of oxygen. The gaseous penetration is not great in so thick a tube, and there is reason to fear the influence of gaseous diffusion to a small extent. The admission of air would be equally sensible if the tube were occupied by coal-gas, or any other foreign gas, instead of being vacuous. As the inner surface of the tube amounted to 0·1034 square metre and the passage of air to 0·8653 cub. centim. per hour, the passage for a square metre would be 8·37 cub. centims. per hour, or 0·14 cub. centim. per minute. The rate of penetration through the tube-walls appears to be one-fifth of what was found for the rubber cloth.

3. *Sheet rubber*, 1 *millim. in thickness.*

Although an increased thickness was no doubt attended by slowness of passage, it was of interest to observe whether the proportion of oxygen per cent. might not at the same time be varied. The sheet used was still, however, as thin as the manufacturer could succeed in cutting from a solid cylinder of wrought rubber by the usual method. The rubber was not vulcanized. The sheet of rubber was made into a bag having 0·149 square metre (231 square inches) of surface, a double thickness of felted carpet being placed within the folds of rubber. A glass quill tube, cemented to the bag, communicated with the interior of the cavity, and was connected at the other end with SPRENGEL'S tube. After the first exhaustion of the gaseous contents of the bag, for which the aid of an exhausting syringe or air-pump is useful, air continued to infiltrate through the sheet rubber, but very slowly. Of the dialyzed air 11·45 cub. centims. were collected in four hours. This air contained 41·48 per cent. of oxygen, with a sensible trace of carbonic acid. The penetration for a square metre amounts to 19·2 cub. centims. of air per hour, or 0·32 cub. centim. per minute.

The same bag, left exhausted for eighteen hours, was found afterwards to yield at once 41·6 cub. centims. of air, containing 40·3 per cent. of oxygen, which had accumulated in the cavity of the bag; therm. about 20° C.

From a larger bag of similar thin sheet rubber, having a surface of 640 square inches, distended by ten or twelve ounces of sawdust, 21·35 cub. centims. of dialyzed air were obtained in one hour; barom. 761 millims., therm. 19°·5 C. This dialyzed air appeared to consist of

Oxygen	41·80
Carbonic acid	0·94
Nitrogen	57·26
	100·00

It does not appear, then, that the increased thickness of the rubber septum tends to increase the proportion of oxygen in the dialyzed air, while this thickness causes the passage to be proportionally slower. The oxygen appears to attain, but never to exceed, at 20° C., the proportion of 41·6 to 58·4 nitrogen.

The thick rubber brings notably into view the carbonic acid of the air. The small proportion of this gas in air is probably increased in all experiments with the rubber septum, however thin. It was observed to rise so high in a small crowded room, as to negative the inflaming action of the oxygen on smouldering wood. But rubber appears to have a power to charge itself gradually from atmospheric air with about half per cent. of its volume of carbonic acid. This carbonic acid, accumulated in thick sheet rubber, appears again to be carried on by the other gases imbibed in a dialytic experiment.

4. *Thin Balloons of india-rubber.*

These little balloons were made available for the dialytic passage of air into a vacuum by filling them with sifted sawdust through a funnel, an operation which requires some address. The balloon collapsed upon the sawdust, which formed an interior ball, the sides of rubber still retaining a thickness of about one-fiftieth of a millimetre. The rubber is not vulcanized. Such a ball, of which the original rubber weighed 0·76 grm., still remained 95 millims. in diameter after the air was exhausted. It was found, when exhausted, to admit 19·6 cub. centims. of dialyzed air in forty-one minutes; barom. 579 millims., and therm. 19° C. The same air possessed 41·32 per cent. of oxygen. The ball had a surface of 0·0283 square metre, and it dialyzed 0·48 cub. centim. of air in one minute. For a square metre of surface this is a passage of 16·9 cub. centims. per minute. The passage therefore is about fifty times as fast as through a sheet of rubber of 1 millim. in thickness, while the high proportion of oxygen is sensibly the same. Such a ball was found to dialyze air in the same manner for more than a month, if protected from mechanical injury.

Three such balls, each containing twenty-three ounces of sifted sawdust, were made to act together, by connecting them with three dependent branches from the same horizontal glass tube. The horizontal tube was connected at one end with an ordinary air-pump which produced a good vacuum by thirty or forty strokes of the piston. The other end of the horizontal glass tube was attached to a good Sprengel apparatus of the largest admissible size, constructed by Messrs. Elliot of the Strand. It was found, however, that the dialyzed air entered rather more rapidly than it could be extracted by a single Sprengel apparatus. This was at the rate of 5 cub. centims. in one minute; therm. about 20° C. The dialyzed air contained 40·5 per cent. of oxygen.

The greatest amount of aërial dialysis per square metre was obtained by means of a rubber bag, larger than usual, and weighing 1·55 grm. When filled with the sawdust and exhausted, this bag still remained of 143 millims. in diameter, and with a surface therefore of 0·0642 square metre. The air which passed through amounted to 17·05 cubic centims. in ten minutes; therm. about 20°. This air gave 40·7 per cent. of oxygen. For a square metre of surface, this is the passage of 26·5 cub. centims. per minute, the highest which has as yet been observed.

In the thin transparent envelope of the little balloon of rubber we have a colloid substance in the most favourable form yet applied to the dialysis of mixed gases. But there is still much room for improvement in the mode of using the thin septum in question. The balls are apt to contract considerably, owing to their elasticity, in the operation referred to, of filling them with sawdust; their walls become at the same time thicker and less quickly pervious. A mode of destroying the elasticity of the membrane when in its most attenuated condition, so that the balloon might be cut open and the membrane spread out without shrinking, would be very useful. Instead of depending upon the interior support of sawdust, the membrane could then be stretched over a more convenient frame to support it, of thin porous deal, of unglazed earthenware, and even of a felted fabric, or several thicknesses of unsized paper supported by a slight frame, so as to form a hollow cavity that admitted of being exhausted of air. The attention of manufacturers of rubber might be advantageously directed to the preparation and proper support of the thinnest possible septa of that material.

The varnish of rubber which appeared to offer the best septum on drying, was a thin solution of rubber in 200 times its weight of chloroform. Four or five coats of this varnish required to be applied to a surface of wood, or of unglazed earthenware, to form an air-tight envelope. The film appeared to exceed in thickness the rubber balloons, and it dialyzed air less rapidly. But a better result may be expected at the hands of experienced manufacturers.

The thin rubber membrane of the balloons was stretched over the ends of glass tubes already closed with a plate of porous stucco—and also over the mouths of small glass bulbs or osmometers, closed with a disk of porous wood or of unglazed earthenware, and which presented a surface of one-hundredth of a square metre. The membrane of the balloon could only be applied while double; but after the covering was securely bound to the glass and cemented with fused gutta percha at the edges, the outer coating was torn off, so as to leave only a single thickness of rubber as the dialytic septum. A bulb of the kind described, when exhausted by a Sprengel pump, gave afterwards 16·36 cub. centims. of dialyzed air in two hours, containing by analysis 41·3 per cent. of oxygen, therm. 23° C.; in the following two hours, 17·35 cub. centims. of air, containing 42·6 per cent. of oxygen. This last is at the high rate, for a square metre of surface, of 14·46 cub. centims. per minute.

5. *Silk cloth varnished with rubber on one side, slightly vulcanized.*

This is a thin but close silk fabric, much used for waterproof garments. It appears also to be employed, when dyed of a fancy colour, in the preparation of artificial flowers and for other purposes. The silk cloth is of a single thickness; and the coating of rubber, which is of a black colour, appears on one side only. It is a much superior material to the ordinary cotton fabrics, which are double, with the two varnished sides pressed together, and is much more to be depended upon for being sound and free from pores than the "waterproof" cotton cloth. The silk cloth, however, should always be tested by examining air dialyzed by means of it. If the proportion of oxygen falls below 40 per cent., the silk is unsound at one or more spots. These spots may generally be discovered by wetting one side of the silk with a sponge and observing where the passage of water is indicated by a visible stain on the other side. The defective spot may be covered by a small disk of sheet rubber applied warm to the surface. Such varnished silk, although not the most rapid in its dialytic action, was more convenient in use than any other septum hitherto tried.

The varnished silk stretched over a disk of porous earthenware (for support) closing the mouth of the small glass bell-jar or osmometer, which has an opening of one hundredth part of a square metre, gave 10 cub. centims. of dialyzed air in one hour, containing 42·2 per cent. of oxygen; barom. 767 millims., therm. 23°·5. For a square metre of surface this is a passage of 2·77 cub. centims. of air per minute.

A small bag, useful for experimental purposes, was constructed of a portion of the same varnished silk, 0·53 metre in length by 0·27 metre in width, which had therefore a surface of 0·143 square metre. The varnished side was turned inwards. Between the folds of the silk was placed a double thickness of common felt carpet or a piece of wadding, so as to occupy the interior of the bag. A glass quill tube also entered the bag to the depth of a few inches, and projected as much outside, so as to admit of being connected, by means of a sound adapter tube of French rubber, with a Sprengel pump, as shown in figure 1 (page 408). The edges of the silk cloth were cemented round by caoutchouc varnish, to a depth of 10 millims., so as to close the bag; and care was taken also to cement the glass tube well to the edges of the bag. When the silk bag is exhausted of air, it remains nearly flat, and feels hard like a piece of cardboard. Such an *air-dialyzer* is further improved by interposing a strong glass flask or bottle, of one or two litres in capacity, between the bag and the pump, so that both are exhausted of air at the same time. The flask must be strong enough to bear the full pressure of the atmosphere without breaking. An auxiliary air-pump, to produce the first exhaustion, cannot well be dispensed with where the space to be made vacuous is so considerable; the Sprengel tube is brought into action afterwards. The advantage gained by the vacuous flask, and even by the thick wadding placed within the bag, is that they form a magazine in which the dialyzed air can be allowed to accumulate for several hours or a whole day, and from which the air may afterwards be drawn quickly by the Sprengel tube for the purpose of experiment. A narrow glass receiver tube, which can be closed by the thumb, may be used to take 5 or 6 cub. centims. for an observation on the inflammation of a chip of wood in the highly oxygenated air. When the proportion of oxygen is under 33 per cent. the wood is not rekindled; but in the ordinary action of this dialyzer the oxygen is seldom found under 40 per cent. The best result is obtained when the exhaustion is within half an inch of the barometric vacuum. When the pressure was allowed to fall to one-half or one-third of an atmosphere, the proportion of oxygen was lessened by 2 or 3 per cent.

The action of heat and cold on the penetrability of rubber is considerable, as has already been stated. Operating with the dialyzing-bag described, without any intermediate flask, the volume of air collected in twenty minutes was 6·35 and 6·57 cub. centims. in two consecutive experiments; barom. 760 millims, therm. 20°. For a square the rate is 2·22 and 2·29, average 2·25 cub. centims. per minute. The proportion of oxygen was, in the first experiment 42·5, and in the second 41·66 per cent.

When the same dialyzing-bag was kept at a temperature of 60° C., the volume of air collected in seven minutes was 6·22 and 7·06 cub. centims. For the square metre this amounts to 6·21 and 7·05, mean 6·65 cub. centims. per minute. The passage of air through rubber is therefore almost exactly three times as quick at 60° as at 20° C.

Again, the dialyzing-bag was kept at 4° C. by being surrounded by ice and salt. The air now collected in seventy-two minutes was 5·78 and 5·77 cub. centims. in volume—for a square metre 0·56 cub. centim. per minute. The passage of air through rubber thus appears to be four times as slow at 4° C. as it is at 20°. The proportion of oxygen in the dialyzed air increased at the same time. In the two portions of air collected at 4° the oxygen was 46·75 and 47·43 per cent. The increase of oxygen at a low temperature was confirmed in other experiments; but it appeared at the same time that the rubber was liable to acquire a true porosity to a slight extent when retained for some hours about 0° C. The rubber then allowed air to pass through it containing no more than 28 or even 23 per cent. of oxygen, and in volume still very small. The rubber has become rigid by the cold, and is now acting feebly as a porous substance, allowing a little gas-diffusion to take place through its substance. Such a condition, which is accidental to caoutchouc at a low temperature, appears to be constant with gutta percha, a harder material, at 20° C., and even higher temperatures.

A large bag of varnished silk with a surface of 1·672 square metre (two square yards) was found still more convenient. It was, however, rather beyond the exhausting-power of the largest Sprengel pump. It yielded in eight minutes, without any collecting-flask, 22, 21·55, and 21·5, mean 21·68 cub. centims. This was a supply of 2·71 cub. centims. per minute, and was at the rate, for a square metre, of 1·62 cub. centim. per minute. The supply would have been about a half more if the dialyzed air had not gained upon the pump. The air of the first and last observations contained respectively 41·89 and 41·85 per cent. of oxygen.

The usual proportion of oxygen in air dialyzed by rubber appears to be about 41·6 per cent.; and it may be described as atmospheric air deprived of one-half of its usual proportion of nitrogen. A single dialysis of air therefore carries the experimenter already halfway from air to pure oxygen as the final result. But the gain by a second dialysis could not be so great, as it would only withdraw one-half of the nitrogen that remained after the first operation, a third dialysis one-half of the nitrogen remaining after the second operation, and so on—each step of the concentration of the oxygen being obtained at a greater cost than the last, and the best conceivable result being only a good approximation. The practical problem which is suggested by the air-dialyzer is, to attain the means on a large scale of reducing to one-half, or so, the proportion of nitrogen in atmospheric air, to be applied to certain useful purposes.

6. *Percolation of air through gutta percha and other septa.*

Thin transparent sheets of a certain material represented as air- and water-tight are in common use. It is often spoken of as consisting of caoutchouc, but appears to have a body of gutta percha, softened probably by a drying-oil. From its softness and thinness, this sheet of gutta percha appeared at first highly promising. But it appears not to be free from small apertures for any considerable surface. When a small sound portion was operated upon, air was found to percolate through it very slowly. In a tube diffusiometer of 1·3 metre in length and 20 millims. in diameter, closed at the top with this septum supported by stucco, the mercurial column fell from 28·7 to 22·625 inches in 18½ hours. The gas which had entered above the mercury measured 13·54 cub. centims., and was found to contain 20·2 oxygen to 79·8 nitrogen—a proof that the air had entered by gas-diffusion. The material is in fact of sufficient porosity to permit the molecular passage of gases in a slow manner.

Varnishes of gelatine and of drying-oil have been tried as dialytic septa, but hitherto without marked results.

PART II.—ACTION OF METALLIC SEPTA AT A RED HEAT.

Platinum.

The surprising passage of gases through the homogeneous substance of a plate of fused platinum or of iron at a red heat, lately discovered by MM. H. STE.-CLAIRE DEVILLE and TROOST, may possibly prove to be analogous in its mode of occurrence to the passage of gases through the rubber septum. At the same time it must be admitted that such an hypothesis as that of liquefaction can only be applied in a general and somewhat vague manner to bodies so elastic and volatile at an elevated temperature as the gases generally must be, and hydrogen in particular. Still some degree of absorbing and liquefying power can scarcely be denied to a soft or liquid substance, in whatever circumstances it may be found, with such a patent fact before us as the retention by fused silver of 18 or 20 volumes of oxygen at a red heat. It may safely be assumed that the tendency of gases to liquefaction, however much abated by temperature, is too essential a property of matter to be ever entirely obliterated.

A little consideration also shows that the absorption of gas by a liquid or by a colloid substance is not a purely physical effect. The absorption appears to require some relation in composition—as where both the gas and the liquid are hydrocarbons, and the affinity or attraction of solution can come into play. May a similar analogy be looked for, of hydrogen to liquid or colloid bodies of the metallic class?

With reference to the mechanical pores of a solid mass, liquids are probably more penetrating than gases. The former show often a power of adhesion to solids, while gases appear to be essentially repulsive. A degree of minute porosity is conceivable, which will admit a liquid, but may be impassable to a gas, even under its molecular movement of diffusion.

Finally, there is presented to us a bold and original conjecture by M. DEVILLE, in explanation of his own observations. It is clearly expressed in the following quotation taken from the last publication of M. DEVILLE on this subject:—

"La perméabilité de la matière est d'une nature toute différente dans les corps homogènes, comme le fer et le platine, et dans des pâtes plus ou moins discontinues, resserrées par la cuisson ou la pression, comme la terre à creuset, la plombagine, dont M. GRAHAM s'est servi dans ses mémorables expériences. Dans les métaux, la porosité résulte de la dilatation que la chaleur fait éprouver aux espaces intermoléculaires; elle est en relation avec la forme des molécules que l'on peut toujours supposer régulières, et avec leur alignement qui détermine le clivage ou les plans de facile fracture des masses cristallisées. C'est cet intervalle intermoléculaire que le phénomène de la porosité des métaux purs et fondus accuse avec une évidence éclatante, c'est aussi par ce phénomène qu'on peut espérer de calculer la distance des molécules solides aux températures élevées où les gaz peuvent s'y introduire."

A new kind of porosity in metals is imagined, of a greater degree of minuteness than the porosity of graphite and earthenware. This is an intermolecular porosity due entirely to dilatation. The intermolecular porosity of platinum and iron is not sufficient to admit any passage of gas at low temperatures, but is supposed by M. DEVILLE to be developed by the expansive agency of heat upon the metals, and to become sensible at the temperature of ignition. Such a species of porosity, if it exists, may well be expected to throw light on the distances of solid molecules at elevated temperatures, when gases introduce themselves. The ready passage through platinum of some gases, particularly of hydrogen, and the difficult passage of others render such molecular views the more remarkable.

The passage of hydrogen through the substance of heated platinum appears in its most simple aspect when the gas is allowed to make its way through the metal into a vacuous space. The experiment of M. DEVILLE, where a tube of platinum charged with nitrogen is placed within a large porcelain tube charged with hydrogen*, was modified by placing the platinum tube, closed at one end, in communication by the other (open) extremity with the Sprengel pump, so that a vacuum was substituted for the nitrogen. It was then easy to observe that a vacuum in the platinum tube was preserved for hours when the external gas admitted into the annular space between the porcelain and platinum tubes was either atmospheric air or hydrogen at the natural temperature. The tubes being placed across an empty furnace, the latter was now lighted; and it was seen that, with air circulating outside the platinum, the vacuum remained undisturbed, even when the temperature of the tubes rose to a bright red heat. But when dry hydrogen was driven through the same annular space, the platinum, while continuing impermeable at all temperatures below a dull red heat, began to admit hydrogen to the vacuum as soon as the external porcelain tube became visibly red-hot. In seven minutes the Sprengel pump now delivered 15·47 cub. centims. of gas, of which 15·27 cub. centims. appeared, by explosion with oxygen, to be hydrogen.

In a repetition of the last experiment, hydrogen dried by sulphuric acid was again allowed to circulate in excess outside the platinum. After a vacuum was once obtained within the platinum tube, the gas delivered by the Sprengel pump, in the cold, during a period of forty minutes, amounted to no more than a bubble of the size of a pin-head, showing the tightness of the apparatus. The Sprengel pump being constantly kept in action, the tubes were now heated to redness, and then gradually to a temperature approaching a white heat. The gas delivered each five minutes was found to be 13, 15·5, 17·4, 16·9, 18·6 cub. centims. as the temperature rose. These volumes are referred to a temperature of 20° and barometer of 760 millims. The last observation gives a passage of 3·72 cub. centims. of hydrogen per minute. The platinum tube employed here was joined without solder, having been drawn from a mass of platinum which had been aggregated by fusion. It was similar in this respect to the tube employed by M. DEVILLE. The tube was 0·812 metre in length (32 inches) and 1·1 millim. in thickness, with an internal diameter of 12 millims. But only a portion of about 200 millims. (8 inches) of the tube were heated to redness in the furnace experiment. The inner surface of the heated portion has therefore an area of 0·0076 square metre. Hence one square metre of heated platinum delivers 489·2 cub. centims. of hydrogen per minute. This result admits of comparison with the passage of gases through a septum of rubber. In the most favourable circumstances, when the thin membrane of a rubber balloon was employed, the passage of air into a vacuum was at the rate of 26·5 cub. centims. per square metre in one minute. The passage of hydrogen may be taken as 4·8 times as rapid as that of atmospheric air, or at 127·2 cub. centims. per minute. But while the thickness of the platinum septum was 1·1 millim., that of the rubber film was only one-seventieth part of a millimetre. Hence we have the ultimate comparison :—

---

* Comptes Rendus, vol. lvii. p. 965.

Passage of hydrogen gas in one minute through a septum of 1 square metre:

Through rubber 0·014 millim. in thickness, 127·2 cub. centims. at 20° C. ;

Through platinum 1·1 millim. in thickness, 489·2 cub. centims. at bright red heat.

If the permeation of hydrogen is due to the same agency in both septa, can the vast superiority of the platinum septum be connected with its greatly higher temperature?

It was interesting now to turn from hydrogen to the passage of other gases through heated platinum. The experiments were all made in the same way, and at a full red heat. The temperature, it will be observed, was short of that at which the elements of water and carbonic acid are partially dissociated.

Oxygen and nitrogen.—Atmospheric air, which may be taken to represent both of these gases, was now allowed to flow through the annular space between the tubes, the interior platinum tube being kept vacuous as usual. In one hour the gas collected by the constant action of a Sprengel pump amounted only to 0·3 cub. centim. Hydrogen in the same time would have given 211 cub. centims. It is very doubtful, too, whether the trifling fraction of a centimetre of gas collected had all passed through the platinum; a part (or the whole of it) may have entered by the joints of the apparatus. Platinum, then, cannot be said to be sensibly permeable to either oxygen or nitrogen, even at a full red heat.

Carbonic acid.—This gas was supplied from a bottle containing marble, by the action of pure hydrochloric acid, the gas being afterwards washed with water and dried by sulphuric acid in its way to the exterior porcelain tube. In one hour the interior platinum tube yielded only three-tenths of a cubic centimetre of gas, of which, again, only an indeterminate small portion was condensed by baryta water and appeared to be carbonic acid. The passage of carbonic acid is therefore incalculably small at a full red heat.

Chlorine.—This gas, evolved slowly from a glass flask containing peroxide of manganese and hydrochloric acid, was washed by water, dried by sulphuric acid, and thrown as usual into the porcelain tube so as to occupy the annular space between the two tubes. A small tube containing slaked lime was interposed between the end of the platinum tube and the Sprengel pump, so as to absorb the chlorine, if any came through the substance of the platinum. After the tube had been heated for an hour, the lime was examined for chlorine, but did not contain a trace of that substance. A minute quantity of gas, probably air, amounting to 0·15 cub. centim., was collected during the time. Platinum, then, is not sensibly penetrated by chlorine at a red heat.

Hydrochloric acid, dried over sulphuric acid, was passed for one hour through the porcelain tube. About 0·5 cub. centim. of gas was collected from the platinum tube, which contained no hydrochloric acid and no free hydrogen. The ignited platinum, then, is not penetrated by hydrochloric acid; nor does it appear to dissociate the elements of that gas at the temperature of the experiment.

Vapour of water.—A stream of steam was carried for one hour through the porcelain tube. During that time half a cub. centim. of gas appeared to be drawn from the platinum tube, which gas contained no hydrogen. There is no evidence of the passage through the platinum of the vapour of water, nor of its decomposition.

Ammonia.—This gas appeared to be decomposed to a considerable extent in passing through the heated annular space, hydrogen passing freely at the same time through the ignited platinum. No trace of undecomposed ammonia, although the gas was transmitted in considerable excess, was discovered accompanying the free hydrogen found in the platinum tube. When the ammonia was evolved slowly, the quantity of hydrogen entering the platinum tube amounted to 16·4 cub. centims. in five minutes, or was sensibly the same as when pure hydrogen was carried through the annular space. Ammonia, then, appears to be incapable of penetrating the ignited platinum.

Coal-gas.—When coal-gas was carried through the porcelain tube, the following quantities of hydrogen came through the platinum in successive periods of twenty minutes each, 13·3 cub. centims., 5·2, and 8·8. The first portion, when exploded with oxygen, did not disturb baryta-water after condensation; 13·3 cub. centims. contained 13·16 cub. centims. of hydrogen. It appears, then, that the permeating gas was free hydrogen only, and that no compound of carbon present in coal-gas was capable of passing through the platinum. This may be held as excluding the passage of *carbonic oxide*, *marsh-gas*, and *olefiant gas*, all represented in the coal-gas.

Hydrosulphuric acid.—This gas, prepared from sulphide of antimony and hydrochloric acid, washed, and dried over chloride of calcium, was then circulated through the outer porcelain tube. The hydrosulphuric acid was nearly all decomposed into sulphur and hydrogen, the latter coming through the platinum at the rate of 9 cub. centims. in five minutes. A trace of hydrosulphuric acid may also have passed through, as the mercury of SPRENGEL'S tube was slightly soiled; but no indication of this gas could be perceived in the hydrogen collected. It, appears, then, that hydrosulphuric acid is to be classed among the non-penetrating gases. The result appears to be:—

I. Gas capable of passing through a septum of platinum 1·1 millim. in thickness at a full red heat.

Hydrogen (211 cub. centims. per hour).

II. Gases incapable of passing through a septum of fused platinum 1·1 millim. in thickness at a full red heat.

Oxygen	(not to the extent of 0·2 cub. centim. per hour.)	
Nitrogen	,,	,,
Chlorine	,,	,,
Hydrochloric acid .	,,	,,
Vapour of water .	,,	,,
Carbonic acid . .	,,	,,
Carbonic oxide . .	,,	,,
Marsh gas (CH_4) .	,,	,,
Olefiant gas . . .	,,	,,
Hydrosulphuric acid	,,	,,
Ammonia . . .	,,	,,

It remains to be discovered whether a sensible passage of any of these gases could be effected through a platinum septum much reduced in thickness, or through the same septum under the influence of a considerably higher temperature. A fallacious appearance of permeation is sometimes occasioned by the escape from the platinum itself of a small quantity of gas, particularly of carbonic oxide and hydrogen, as will immediately appear. The permeation is in consequence never unequivocal for the first hour or two that the platinum septum is heated.

One of the curious experiments of M. DEVILLE was repeated, in which hydrogen appears to escape from the platinum tube pretty much as the same gas would escape from a graphite diffusiometer—the platinum tube being full of hydrogen, while the annular space between the platinum and outer porcelain tube was occupied by atmospheric air. At the maximum temperature the supply of hydrogen to the platinum tube was shut off, as that gas entered at one end of the tube, while the other end of the platinum tube was left in connexion with a barometer-tube dipping into a cistern of mercury. Immediately the mercury began to rise in the gauge tube from the passage of hydrogen outwards through the walls of the platinum tube; and the latter in the end became nearly vacuous from the complete escape of the hydrogen.

Heated platinum tube containing hydrogen; air outside.

Time.	Rise of mercury in gauge barometer.
0 minute.	0 millim.
10 minutes.	115 millims.
20 „	245 „
30 „	400 „
40 „	535 „
50 „	645 „
60 „	710 „

the actual height of the atmospheric barometer being 750 millims. at the same time. The tension of the residual gas was therefore no more than 40 millims. of mercury. The ratio between the volume of gas at the beginning and end of the hour is here as 18·75 to 1; whereas in a diffusion experiment of hydrogen into air, the ratio would be as 3·8 to 1. Further, the residual gas in the platinum tube still retained a small portion of hydrogen. Withdrawn by means of the Sprengel pump and examined, the residual gas in the platinum tube amounted to 3·56 cub. centims., and consisted of

Nitrogen	3·22	cub. centims.
Hydrogen	0·34	„
	3·56	„

The available capacity of the platinum tube was 113·1 cub. centims.; and when the tube was heated, the gas driven out by dilatation measured in the cold 39·5 cub. centims., leaving in the hot platinum tube 73·6 cub. centims. of gas estimated at 20° C. and barom. 760 millims. It was found necessary in these experiments to stuff that portion of the platinum tube that was placed across the furnace and strongly heated, with asbestos, to give support to the tube when softened by the heat of ignition, and to prevent the tube from collapsing.

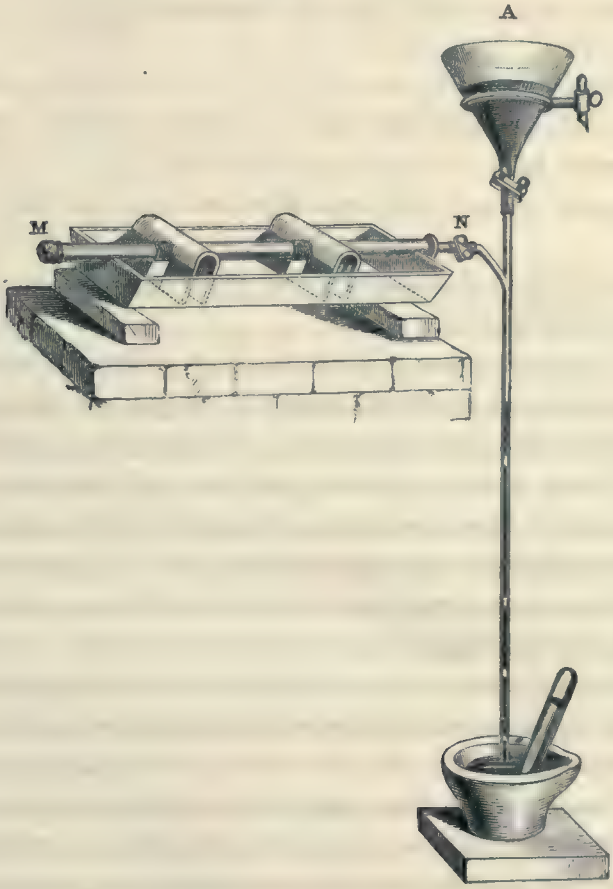
It is difficult to say where the small volume of nitrogen found in the platinum tube, amounting to 3·22 cub. centims., actually came from. It appears too great in amount to have formed an impurity in the original hydrogen gas, or to have gained access to the vacuum through defective joinings in the apparatus. Its presence suggests the inquiry, admitting that nitrogen cannot pass alone through platinum into a vacuum, whether the same gas may not be enabled to pass, in some small proportion, while hydrogen is simultaneously travelling through the platinum in the opposite direction. The liquid or the gaseous hydrogen occupying the platinum septum would thus form a vehicle or channel, by the help of which another analogous body like nitrogen might be conceived capable of passing through the platinum in small quantity, by a process of liquid or gaseous diffusion.

Absorption and detention of Hydrogen by Platinum.—The passage of a gas through a colloid septum is preceded by the condensation of the gas in the substance of the septum, according to the views taken in this paper. Is a plate of ignited platinum capable, then, of condensing and liquefying hydrogen gas? The subject could scarcely admit of experimental investigation without the application of the same useful air-exhauster that was employed with the non-metallic colloids. The metal was always treated in the same manner; so that a description of the details of one experiment will apply to all*.

Platinum wire or plate being provided, the surface of the metal was first divested of all adhering oily matter, by boiling in caustic alkali and afterwards in distilled water.

The platinum, generally in the form of wire, was then introduced into a porcelain tube M, N (fig. 2), glazed both outside and inside, 0·55 metre in length and 23 millims. in internal diameter. This tube could be heated either by means of the combustion-furnace used for organic analysis, or by placing the tube across the chamber of a small

Fig. 2.



---

* Platinum in the peculiar condition of platinum-black absorbs 745 times its volume of hydrogen gas.—Traité de Chimie Géneralé, par MM. PELOUZE et FRÉMY, t. iii. p. 398.

cylindrical furnace. The porcelain tube was fitted at both ends with perforated corks, well cemented with fused gutta percha, and provided each with a small quill tube. Such may be described as the distillatory apparatus employed. It was connected at the end N with the Sprengel pump A B, to be used as an exhauster and transferrer of gas, by means of good caoutchouc adapters (not vulcanized), and at the other end, M, with the apparatus for supplying dry hydrogen, atmospheric air, or any other gas. By a screw clamp upon the adapter at M, the tube could be closed, and the gas-producing apparatus then detached, leaving the porcelain tube shut at one end. A tube of the hard glass used in combustion analysis, may be substituted for the porcelain tube in many such experiments. A less degree of heat suffices than was at first supposed.

The porcelain tube is exhausted by continuing the action of the Sprengel for ten or fifteen minutes, till small bubbles of gas cease to be delivered by the tube A B in the mercurial trough below. The sufficiency of the joints is thus first ascertained. Heat being then applied to the porcelain tube, its impermeability at a red heat will also be tested.

The platinum, when introduced, was confined to about two-thirds of the central portion of the porcelain tube, which could be conveniently heated. The apparatus obviously affords the means both of heating the platinum in a vacuum and also in an atmosphere of hydrogen or any other gas admitted into the interior of the porcelain tube at M.

Fused platinum.—Articles of manufactured platinum appear now to be prepared exclusively from the fused metal.

1. A quantity of clean platinum wire from fused metal, measuring 0·695 metre in length, 4·1 millims. in diameter and 201 grms. in weight, was bent and introduced into the porcelain tube, which was then exhausted. The platinum was first heated alone for an hour to drive off any natural gaseous product, and then dry hydrogen gas was admitted to the porcelain tube, the gas being evolved from pure sulphuric acid and pure zinc. The hydrogen was conveyed in excess into the porcelain tube, at a cherry-red heat, and the temperature was then allowed to fall in a gradual manner—a procedure which was found to promote the absorption of the gas. The platinum was thus retained for about twenty minutes in an atmosphere of hydrogen, at a temperature partly above and partly below dull redness, terminating with the lower temperature. After the fire was withdrawn and the tube allowed to cool, air or nitrogen was driven through it, and all free hydrogen thus expelled from the apparatus.

The closed tube was now exhausted in the cold, but no hydrogen came off. The platinum being still retained in a good vacuum, heat was again very gradually applied, and the action of the Sprengel pump maintained. Simultaneously with the first appearance of visible ignition, gas began to be evolved. In one hour, the porcelain tube being heated to redness, 2·12 cub. centims. of gas were collected, of which about one-third was collected in the first ten minutes. It was found, by explosion with oxygen, to consist of—

Hydrogen	1·93 cub. centim.
Nitrogen	0·19 „

Now, taking the specific gravity of the platinum wire at 21·5, the volume of 201 grms. of metal will be 9·34 cub. centims. Hence one volume of platinum held, the gas being measured cold,

0·207 vol. hydrogen.

The platinum did not appear sensibly altered in lustre, or in any other way, by its relation to the hydrogen.

2. The same piece of platinum wire was drawn out into four times its first length, and the experiment of charging with hydrogen was repeated. The platinum gave up at a red heat, maintained for one hour, 1·8 cub. centim. of gas, of which 1·6 cub. centim. was hydrogen. Here one volume of platinum appears to have held

0·171 vol. hydrogen.

The absorption of hydrogen has not been increased by increasing the surface of the metal.

In two further experiments upon the same platinum wire, the volume of hydrogen retained by one volume of platinum was—

3.	0·173 cub. centim. hydrogen.
4.	0·128 „ „

There is an evident tendency of the hydrogen taken up to diminish in quantity. These experiments have the advantage for comparison with the earlier observations on the penetration of a platinum septum by hydrogen gas, that both wire and tube had been drawn out from the same mass of fused metal. No iridium had been added to this platinum, as is sometimes done to increase the elasticity of the metal. The absorption of hydrogen is small, amounting, according to the mean of the four observations, to 17 per cent. of the volume of the platinum. At the temperature of a low red heat, when the absorption took place, the gas would be considerably dilated, to the extent of at least three times its volume stated above, or to about 51 per cent., half the volume of the platinum. It is to be considered whether an absorption of half a volume of gas would be sufficient to account for the observed penetration of a septum of metal 1·1 millim. in thickness. The data appear to favour an affirmative conclusion; but their value cannot be very decidedly estimated.

It appears necessary to recognize in platinum a new property, a power to absorb hydrogen at a red heat, and to retain that gas at a temperature under redness for an indefinite time. It may be allowable to speak of this as a power to occlude (to shut up) hydrogen, and the result as the *occlusion* of hydrogen by platinum.

The observation was extended to platinum in other conditions of form, but where, it is to be observed, the metal had not been fused, but only welded, and was not of recent manufacture.

5. Of the grey pulverulent spongy platinum, prepared from the ammonio-chloride,

22·2 grms. were heated by the combustion-furnace, and for half an hour allowed to cool gradually in dry hydrogen gas, as in the preceding experiments. The volume of the platinum is 1·032 cub. centim. by calculation. In the first experiment it yielded to heat and the action of the Sprengel pump 2·2 cub. centims. of a gas which burned like hydrogen. In a second experiment the platinum yielded in one hour (when it appeared to be exhausted) 1·7 cub. centim. of gas, found by explosion to consist of hydrogen 1·52 cub. centim., and nitrogen 0·18 cub. centim. Here one volume of spongy platinum appears capable of occluding

1·48 vol. hydrogen.

6. Wrought platinum, in the form of plate from an old crucible cut up, after washing and ignition, was charged with hydrogen three times in succession. The weight of the platinum was 24·1 grms., and its volume 1·12 cub. centim. It yielded in seventy-five minutes 4·19 cub. centims. of gas, and in thirty minutes further 1·5 cub. centim. more, making together 5·69 cub. centims., of which 4·94 cub. centims. proved to be hydrogen; therm. 14°·2, barom. 760 millims. Not a trace of carbonic acid was found in the gas before or after explosion. Again, after a second charge, 5·12 cub. centims. of gas were given up in an hour, of which 4·4 were hydrogen; and lastly, 3·76 cub. centims. in an hour, of which 3·42 were hydrogen. Hence, occluded by 1 vol. wrought platinum—

5·53 vols. hydrogen.
4·93 „ „
3·83 „ „

The volume of occluded hydrogen is much larger than in the fused platinum, or even in the spongy platinum. It exhibits a tendency to fall off on repeating the experiment. The declension in absorbing-power may possibly be connected with the reduced duration of the exposure to hydrogen of the metal while cooling.

7. Wrought platinum, which had been formed many years ago into a small tube, weighing 64·8 grms., 0·322 metre in length and 5 millims. in diameter, was cut into three equal lengths for convenience in placing the metal within the porcelain tube, to be heated and charged with dry hydrogen. By an hour's exhaustion afterwards the platinum yielded 9·2 cub. centims. gas, of which 8·9 were hydrogen. The volume of the platinum itself was 3·9 cub. centims.; and one volume of metal had therefore occluded 2·28 vols. hydrogen, measured at about 20° C. In all such experiments, besides blowing out the free hydrogen by air, the apparatus was also thoroughly exhausted by the Sprengel pump in the cold, before the occluded hydrogen was extracted.

The lustre and appearance of the metallic platinum was not altered by the ingress of the hydrogen; but after the escape of the gas the platinum appeared whiter in colour, and the surface was covered by minute blisters.

Repeating the experiment, the gas collected by an hour's exhaustion was 8·7 cub. centims., of which 8·46 cub. centims. were hydrogen. Here the metal occluded 2·8 vols. of hydrogen.

The same platinum was a third time charged with hydrogen; but on this occasion the platinum was placed in a tube of hard glass, and the tube connected with the air-exhauster. The glass tube was heated by an oil-bath, and the platinum kept *in vacuo* at a temperature of 220° C. for an hour. Not a bubble of gas was evolved. The glass tube was afterwards heated by a small Bunsen burner, which was calculated to give a degree of heat little short of visible redness, still no hydrogen came off. The tube was now heated sufficiently to soften glass (500°). Gas began to come off, of which 1·8 cub. centim., containing 1·72 hydrogen, were collected in ten minutes. The glass tube having cracked, the whole apparatus was allowed to cool, and the platinum transferred to a porcelain tube. Further heated by a combustion-furnace for one hour, the platinum gave off 8·6 cub. centims. gas, of which 8·2 were hydrogen. The platinum therefore appears to have occluded altogether 3·79 vols. of hydrogen.

The preceding experiment appeared to show a complete sealing up of the occluded hydrogen at low temperatures, seeing that, although nearly four volumes of gas were present, none escaped below a red heat. But to test the effect of time at the temperature of the atmosphere, the platinum, again charged with hydrogen, was sealed up hermetically in a glass tube, which it nearly filled, and not opened for two months. The air in the tube was was then transferred and examined. It did not exhibit any reduction of volume under the electric spark or a pellet of spongy platinum. The air therefore appeared to contain no hydrogen; the latter had not diffused out, but, it is to be presumed, was retained by the platinum without loss. These experiments, although related last, were the first performed in this inquiry. The included hydrogen was never entirely extracted in an hour, and is probably understated. The gas always came off gradually, more than one half of the whole in the first twenty or thirty minutes. The last results may be stated as follows:—

1 vol. hammered platinum occluded 2·28 vols. hydrogen.
„ „ „ 2·80 „
„ „ „ 3·79 „

The high absorbing power of the hammered platinum, or rather the low absorbing power of the fused metal, was ascribed to a mechanical difference between the two—to a more open texture in the former, permitting more free access of hydrogen, liquefied as it may be, to the interior of the metal.

8. The extrication of occluded hydrogen from platinum had always required a degree of temperature verging upon a red heat, even when aided by a vacuum; and this remains true of hydrogen originally absorbed at or near a red heat. But the fact appears to be compatible with the absorption of the gas, under the pressure of the atmosphere, at a considerably lower temperature. Thin platinum-foil was first deprived of a little natural gas by ignition *in vacuo* in the porcelain tube. The foil was afterwards placed in a glass tube and heated again in a stream of hydrogen, to a temperature not exceeding 230° C., for three hours, by means of an oil-bath, and further allowed to cool slowly in an atmo-

sphere of the same gas for several hours. A second glass tube receiver, to which the platinum-foil was transferred, was exhausted, as usual, at 20° C. without any sensible evolution of gas. With a red heat superadded, gas came off in twenty minutes (but nearly all in the first seven minutes) to the extent of 0·75 cub. centim., of which 0·56 cub. centim. proved to be hydrogen. The volume of 8·3 grms. of platinum is 0·385 cub. centim. Hence one volume of platinum foil appears to take up, in three hours,

1·45 vol. hydrogen at 230° C.

9. The same portion of platinum-foil was again charged with hydrogen at a still lower temperature, namely between 97° and 100°, for three hours. Submitted to exhaustion at red heat, the platinum now gave off 0·5 cub. centim. of gas in thirty-five minutes, of which about 0·3 cub. centim. were hydrogen. One volume of platinum-foil has taken up

0·76 vol. hydrogen at 100°.

By this property platinum is connected with palladium, which of all metals appears to possess the power of absorbing hydrogen in the highest degree.

Palladium.

Of late years palladium has become comparatively uncommon; and some difficulty was experienced at first in procuring more than a gramme or two of the metal, in the form of thin foil. The palladium-foil first employed weighed 1·58 grm., and measured 0·133 cub. centim., taking the specific gravity of the metal at 11·86, and had a surface of 0·00902 square metre. It gave off, when heated *in vacuo* for one hour, 1·50 cub. centim. of natural gas, containing no compound of carbon, but consisting of hydrogen and air.

1. As it appeared from preliminary experiments that the occlusion of hydrogen by palladium was likely to be a phenomenon exhibited at a comparatively low range of temperature, the metal was heated in hydrogen no higher than 245° C., by an oil-bath, and allowed to cool very slowly, so as to pass through still lower ranges of temperature which might be favourable to the absorption of hydrogen. The metal, when afterwards transferred to the distillatory glass tube, appeared to give out nothing to a vacuum at 17°·8 C. and barom. 759 millims. But the moment the combustion-furnace was lighted under the tube, gas come off most freely. Of the first portion collected, 11·77cub. centims. contained 11·74 cub. centims. hydrogen. The gas ceased to be evolved in fifteen minutes, when 69·92 cub. centims. were collected, of which the greater part came over in the first ten minutes. Hence palladium has taken up a large volume of gas when the temperature of the metal never exceeded 245° C.

1 vol. palladium held 526 vols. hydrogen.

2. In a similar experiment the temperature of absorption was still further lowered with good effect. The palladium was exposed to hydrogen between 90° and 97° C. for three hours, and then allowed to cool in the gas for one hour and a half. Now placed in a glass tube, exhausted, and heated by a gas-flame, the palladium gave off gas in a

continuous stream for twelve minutes, when it ceased. The gas amounted to 85·56 cub. centims., of which 96·8 per cent. was hydrogen; therm. 17°·5, barom. 764 millims.

1 vol. palladium held 643·3 vols. hydrogen.

By the care of my zealous assistant, Mr. W. C. ROBERTS, the hydrogen employed in these experiments was purified to the highest degree by passing it in succession through alcohol, water, caustic potash, and tubes of 0·7 metre each, filled with broken glass impregnated with nitrate of lead, sulphate of silver, and oil of vitriol. The gas was inodorous, and burned with a barely visible flame.

No alteration was sensible in the metallic appearance of the palladium-foil when charged with hydrogen, or when discharged. The foil was much crumpled and rather friable after repeated use; but this may have arisen from frequent handling.

3. Palladium appears to absorb hydrogen largely, even at natural temperatures, provided that the metal has been recently ignited *in vacuo*. The foil, without such preparation, was placed in a bottle of pure hydrogen for several hours, but yielded nothing when afterwards ignited in the Sprengel vacuum. The foil, however, being immediately returned after cooling to a stoppered bottle containing hydrogen, and left in the gas for a night, absorption now took place—air rushing in, on opening the stopper, as into a partial vacuum; therm. 19°. When the palladium-foil was afterwards transferred to a glass tube and connected with the Sprengel pump, it was found difficult to obtain a vacuum for some time, owing to hydrogen coming off at the temperature of the atmosphere. But after a fair vacuum was produced 6·96 cub. centims. were collected, of which 6·78 proved to be hydrogen. Heat was then applied, and 42 cub. centims. came over in five minutes, making altogether more than 50 cub. centims., or 376 volumes of gas. The absorption of hydrogen appears, then, to be suspended at a low temperature, unless the condition of the metal be favourable. The action of a plate of clean platinum in determining the combustion of explosive gas is equally critical at a low temperature.

4. A different specimen of palladium-foil, weighing 5·76 grms., and having a volume of 0·485 cub. centim., was charged with hydrogen, and discharged, more than once. In the second experiment, the foil was heated in hydrogen at 100° for three hours. Distilled afterwards in a porcelain tube at a low red heat in the usual way, the palladium was found to have absorbed, at 100°,

347·7 vols. of hydrogen measured at 18°·2 C. and barom. 756 millims.

5. So large an absorption of hydrogen should increase the weight of the palladium sensibly, notwithstanding the lightness of the gas. One litre, or 1000 cub. centims., of hydrogen at 0° C. and 760 millims. weighs 0·0896 grm. Of new palladium-foil, believed to be from *fused* metal, 5·9516 grms. increased to 5·9542, or by 0·0026 grm., when the metal was charged with hydrogen at 100° for four hours. This amounts to only 29·01 cub. centims. of hydrogen at 0° C. and 760 millims. barom. The gas actually extracted afterwards from the palladium did not exceed 34·2 cub. centims. at 19° C., and barom. 758 millims., equivalent to 31·84 cub. centims. at 0° C. and 760 millims.

barom. The whole gas extricated (68 vols.) seems unusually small, but it corresponds closely enough with the volume calculated from the increase of the palladium in weight. An inferior absorbing power for hydrogen appears to be connected in both platinum and palladium with the fusion of the metal.

6. A portion of similar palladium-foil, charged with hydrogen, was found to have its gas reduced from 20·7 to 16·2 cub. centims. after exposure to the air for forty-two hours. The liquid hydrogen, whether held by the substance or in the pores of the metal, appears therefore to evaporate slowly at the temperature of the atmosphere, therm. 19°, barom. 752 millims.

7. Spongy palladium, from the ignition of the cyanide, being heated in hydrogen at 200°, and allowed to cool slowly in the same gas for four hours, the metal was found to have taken up 686 vols. of hydrogen.

Treated in a similar manner with air, spongy palladium exhibited no absorbing-power for oxygen or nitrogen.

Hydrogen, condensed either in the palladium sponge or foil, was observed to have its chemical affinities enhanced. The palladium being placed in dilute solutions of the following substances for twenty-four hours in the dark at the ordinary temperature, the action of the hydrogen became manifest.

Persalt of iron became protosalt.

Ferricyanide of potassium became ferrocyanide.

Chlorine-water became hydrochloric acid.

Iodine-water became hydriodic acid*.

Apart from hydrogen, the palladium sponge exhibits a power of selection and absorption of alcohol in preference to water. 30 grms. of the sponge were left in contact with 9·5 cub. centims. of dilute alcohol of specific gravity 0·893, for fifty-one hours, sealed in a tube. The supernatant liquid now drawn off to the extent of 3·9 cub. centims. was of specific gravity 0·901, while the portion retained by the palladium was found when distilled to be of specific gravity 0·885, or it was sensibly concentrated. This chemical action of palladium sponge was more than once verified. Platinum sponge, on the other hand, exhibited no indication of a similar separating-power; nor did the sponge of iron reduced by hydrogen from the oxide.

8. Connected, it may be, with this chemico-molecular action of palladium is the variable absorptive power for different liquids exhibited by palladium-foil. Immersed in various liquids for an hour, and afterwards dried by pressure for a few seconds between folds of blotting-paper, a quantity of palladium-foil represented by 1000 was found to retain in its pores—

Of Water	1·18 part.
Of Alcohol (0·802)	5·5 parts.

---

* The power of platinum-black charged with hydrogen to communicate the latter element to organic compounds has lately been observed by M. P. de Wilde, following Dr. Debus.—Bulletin de la Société Chimique, Mars 1866.

Of Ether	1·7	part.
Of Acetone (0·794)	0·54	„
Of Glycerine	4·5	parts.
Of Benzol	3·5	„
Of Oil of sweet almonds	18·1	„
Of Castor-oil	10·2	„

The superior penetrativeness of alcohol over water is well marked; capillary action appears to merge into a chemical affinity. Liquid hydrogen would also appear as highly absorbable by palladium-foil. It would appear also to be separable from other gases (or liquids), as alcohol is from water, by the palladium-pores.

Alloy of 5 *palladium and* 4 *silver.*—The power to absorb hydrogen appears to extend to this alloy of palladium. A plate of the alloy, about 180 millims. in length, 31 millims. in width, and weighing 74·3 grms., was bent, so as to be able to enter a wide porcelain tube that could be exhausted of air when required. The volume of the palladium alloy was 6·21 cub. centims. The plate of metal being placed in the porcelain tube, had hydrogen gas passed over it at a low red heat for one hour, and was then allowed to cool slowly in the same gas. Taken out and examined, the metal was not visibly altered. For the extrication of gas the metal was distilled in the porcelain tube heated by jets of gas, and connected with the Sprengel pump, as usual. In seven minutes after the gas-furnace was lit, 24 cub. centims. of gas came off; in ten minutes more, 80·71 cub. centims.; and in seventy-five minutes more, 36·75 cub. centims., making altogether 141·46 cub. centims. Of this gas 127·74 cub. centims. proved to be hydrogen, the remainder being nitrogen, derived, no doubt, from the large imperfectly exhausted porcelain tube. The palladium alloy, in the form of a thick plate, appears therefore to have held

20·5 vols. hydrogen, measured at 18°·2 and barom. 756 millims.

This alloy of palladium becomes crystalline by heating, and appears to lose much of its absorbent power at the same time.

The conclusion, then, is that welded palladium, in the condition of thin foil, readily absorbs hydrogen, to the extent of upwards of 600 times the volume of the metal at a temperature under the boiling-point of water, upwards of 500 volumes at 245°, and less at higher temperatures, the metal being always surrounded by hydrogen under atmospheric pressure. Hydrogen is also largely absorbed, although less constantly, at ordinary temperatures. On the other hand, palladium already fully charged with hydrogen at or under 100°, and under the pressure of the atmosphere, begins to give out gas when exposed either to atmospheric air or to a vacuum at the original temperature of absorption; and the gas is freely discharged at 200° C.

It is probable that hydrogen enters palladium in the physical condition of liquid, whether the phenomenon proves to be analogous to the imbibition of ether, chloroform, and such solvents by the colloid india-rubber, or whether a certain porosity of structure in the palladium is required. The porosity of the metal is supposed to be of that high degree which will admit liquid but not gaseous molecules. Now the numerous liquid compounds of carbon and hydrogen have all a nearly similar density, generally a little under that of water. There is no reason to suppose that the density of liquid hydrogen would differ greatly from the hydrocarbon class; but then the surprising lightness of hydrogen gas must cause liquid hydrogen to yield a volume of vapour disproportionately large when compared with the former class of substances, or, indeed, with any other substance whatever. The absorption of hydrogen by palladium will appear, then, less extravagantly great when viewed as the absorption of a highly volatile liquid capable of yielding an exceedingly light vapour, rather than that of a gas.

An excellent opportunity of observing the penetration by hydrogen of a compact plate of palladium, 1 millim. in thickness, was afforded by a tube of that metal constructed by Mr. MATTHEY. This tube was said to have been welded from palladium near the point of fusion of the metal. The length of the tube was 115 millims., its internal diameter 12 millims., thickness 1 millim., and external surface 0·0053 of a square metre. It was closed by thick plates of platinum soldered at both ends, one of the plates being perforated by a long small tube of platinum, by which the cavity of the palladium tube could be exhausted of air.

Now the closed palladium tube remained air-tight, when exhausted by the Sprengel tube, at the ordinary temperature, at 260°, and at a temperature verging on low redness, the gas without being atmospheric air. Hydrogen being then substituted as the external gas, the walls of the palladium tube still remained impermeable at a low temperature. No hydrogen gained the interior in three hours at 100°. But the temperature being gradually raised by means of an oil-bath to 240°, hydrogen then began to come through, and at a gradually increasing rate to 265°. The hydrogen then entered steadily at the rate of 8·67 cub. centims. in five minutes. This gives a rate of 327 cub. centims. for a square metre of surface per minute. Heated to a temperature just short of redness, the passage of hydrogen was increased to 11·2 cub. centims. in five minutes, or 423 cub. centims. for a square metre per minute.

With coal-gas as the external atmosphere the penetration of the palladium began about the same temperature, and was continued at 270° at the rate of 57 cub. centims. for a square metre of surface per minute. The penetrating gas had no odour of coal-gas, contained no trace of carbon, and appeared to be absolutely pure hydrogen. The exact isolation of the latter gas by septa of both platinum and palladium appears most extraordinary.

A quantitative determination of the hydrogen in a gaseous mixture could probably be effected by means of the hollow cylinder of palladium.

Is the power to penetrate the metals in question confined to hydrogen? It has been lately concluded by Dr. C. WETHERILL that the turgescence of the ammonium amalgam depends entirely upon the retention of hydrogen gas-bubbles*; hydrogen, then, appears to exhibit an attraction of a peculiar kind for mercury. The ready liquefaction of the same gas by the platinum metals evinces also a powerful mutual attraction. The only other volatile body which has been observed to pass, like hydrogen, through a plate of palladium is common ether—and that at the atmospheric temperature, while a passage was denied to hydrogen at the same time. The palladium was in the form of foil. Although thin foil of this metal is generally visibly porous and allows air to pass through like a sieve, a tube diffusiometer, covered with a disk of the selected palladium foil, and standing over mercury, retained a volume of 40·5 millims. of air over a vertical column of 155 millims. of mercury for twenty-four hours without depression of the mercury. The air was dried by sticks of potash, but still it did not penetrate the palladium. Dry hydrogen was then conducted to the upper surface of the palladium disk, but still without any penetration by that gas after several hours. Cotton-wool moistened with ether was now placed upon the disk, when, after eight minutes, the confined air within the tube began to expand; and in the course of an hour longer, the 40·5 volumes of confined air increased to 90·4 (thermometer 18°·5, barometer 758), when the expansion ceased. The increase of volume appeared to be due entirely to ether-vapour, absorbable by a pellet charged with sulphuric acid. Why hydrogen proved to be incapable of penetrating the palladium in such circumstances it is difficult to say. It can only be imagined that the palladium foil may have previously condensed on its surface a minute film of foreign matter, which rendered the palladium inactive to hydrogen but not to ether-vapour.

---

* American Journal of Science, vol. xlii. No. 124.

On the other hand, the penetrating power of hydrogen, here referred to the liquefaction of that gas, appears not to be solely confined to metallic septa. There is reason to suspect that in diffusing through a plate of graphite hydrogen passes in a small proportion as a liquid, without any counterdiffusion of air. Hence the constant excess observed of the diffusive coefficient of hydrogen, which came out 3·876, 3·993, and 4·067 *, instead of the theoretical number 3·8, corresponding to the density of the gas referred to air. Such phenomena of gaseous penetration suggest a progression in the degree of porosity. There appear to be (1) pores through which gases pass under pressure or by capillary transpiration, as in dry wood and many minerals, (2) pores through which gases do not pass under pressure, but pass by their proper molecular movement of diffusion, as in artificial graphite, and (3) pores through which gases pass neither by capillary transpiration nor by their proper diffusive movement, but only after liquefaction, such as the pores of wrought metals and the finest pores of graphite.

Osmium-iridium.

A portion of small grains of osmium-iridium, amounting to 2·528 grms., was exposed to hydrogen through all descending temperatures from a red heat, as the preceding metals had been treated. The osmium-iridium was then heated again to redness in the Sprengel vacuum, to extricate any hydrogen that might have been absorbed. But only a bubble or two of gas, too minute to be measured, passed over in fifteen minutes, at a red heat. Osmium-iridium, then, exhibits no absorbent power for hydrogen—a result which is consistent with the crystalline character of the substance.

---

* Philosophical Transactions, 1863, p. 404.

Copper.

The power to occlude gases appears not to be confined to palladium and platinum among the metals. The exact experiments of M. Dumas, by which the atomic weights of the leading elements were definitely settled, afford an indication of the absorption of hydrogen gas by spongy metallic copper reduced from the oxide, sufficient to affect the weight of the metal to the extent of about 3 parts in 100,000[*].

1. With the view of applying the method of extracting gas followed in the treatment of the preceding metals, so much oxide of copper was reduced by hydrogen as was calculated to yield 50 grms. of metallic copper. The reduced metal was again heated to redness and slowly cooled in a stream of dry hydrogen. After free exposure to the air for a few minutes, the metal was now submitted, at a red heat, to the action of the Sprengel pump. It then gave off in one hour 3·35 cub. centims. of gas, measured cold, which appeared to be pure hydrogen (the explosion with oxygen indicated 3·4 hydrogen). Taking the specific gravity of copper at 8·85, 50 grms. of that metal would be 5·65 cub. centims. in volume, and the result is that

1 vol. reduced copper sponge occludes 0·6 vol. hydrogen.

Hydrogen being about 12,000 times as light as copper (at 15°), 1 part of gas by weight has been taken up by 20,000 parts of metal.

2. The same weight and volume of fine copper, in the form of wire, thoroughly cleaned, was exposed to hydrogen at a red heat, and then submitted to exhaustion for one hour. It gave 2·6 cub. centims. gas, of which 2 cub. centims. were hydrogen, and the remaining 0·6 principally carbonic oxide. It may be represented that

1 vol. wrought copper occludes 0·306 vol. hydrogen.

Where a metal, such as wrought copper, may contain small quantities of carbon and oxygen, an obvious cause will exist for the production and evolution of carbonic oxide under the influence of heat. Gas so generated appears to be added to the occluded hydrogen when extricated, in the last experiment.

Gold.

1. A quantity of gold was precipitated from the assay cornettes used below by means of oxalic acid. The gold weighed 93·3 grms., with a volume of 4·83 cub. centims., taking the specific gravity of the metal as 19·31. Exhausted at a red heat without any further treatment, the reduced gold yielded 3·4 cub. centims. of gas, which may therefore be supposed to be gas usually present in gold reduced in the manner described. This is 0·704 vol. of the gold. The occluded gas in precipitated gold gave to analysis

---

[*] Annales de Chimie et de Physique, 3 sér. t. viii. p. 205. The observations of M. Melsens show that 240 grms. of copper may fix about 0·007 grm. of hydrogen, most being fixed when the oxide of copper is reduced by hydrogen at a low temperature. In the subsequent oxidation of the copper the gas does not come out suddenly, but in a gradual manner.

0·05	cub. centim.	Oxygen.
1·50	,, ,,	Carbonic acid.
1·85	,, ,,	Carbonic oxide, &c.
3·40		

2. Of the original cornettes of fine gold, from gold assays conducted several months before, 93·3 grms., having a volume of 4·83 cub. centims., were submitted without any further treatment to aspiration at a red heat. The gold gave up in the first half hour 9·45 cub. centims. of gas, and in the second half hour 0·8 cub. centim., making together 10·25 cub. centims. Hence 1 volume of the gold cornettes appears to hold 2·12 volumes of gas. This gas consisted of

6·70	cub. centims.	Carbonic oxide.
1·50	,, ,,	Carbonic acid.
1·58	,, ,,	Hydrogen.
0·44	,, ,,	Nitrogen.
0·03	,, ,,	loss.
10·25		

The cornettes do not appear ever to assume again so much gas as they first acquired in the assay muffle. It follows that the weight of a gold cornette is increased about 2 parts in 10,000 by the weight of occluded gas. As the gold also retains 7 or 8 parts of silver in 10,000, it follows that the absolute quantity of gold in a cornette is less than the weight of the cornette as indicated by the balance, by 1 part in 1000. This does not disprove the accuracy of the usual gold assay, which is always made in comparison with gold of known composition as a check, and is therefore *relatively* true.

3. The same volume of gold cornettes, amounting to 4·83 cub. centims., heated again in carbonic oxide gas, gave up afterwards 1·6 cub. centim. of occluded gas, composed of

1·4	cub. centim.	Carbonic oxide.
0·2	,, ,,	Carbonic acid.
1·6		

4. The same mass of gold cornettes heated in hydrogen gas, gave up afterwards in one hour 2·7 cub. centims. of gas, which appeared to consist of

2·34	cub. centims.	Hydrogen.
0·36	,, ,,	Nitrogen, &c.
2·70		

The power of this metal to occlude hydrogen gas is very sensible. The metal here appears to hold 0·48 volume of hydrogen gas. The same gold, when dissolved and precipitated, was also found capable of holding 0·44 volume of hydrogen.

5. The same mass of cornettes, heated in carbonic acid gas, gave up afterwards in one hour 1·05 cub. centim. gas, in which baryta-water showed the presence of

0·78 cub. centim. Carbonic acid.

The charged cornettes were always freely exposed to air for some time before occluded gas was extracted from them and measured, so as to allow the escape of any loosely attached gas.

6. The same cornettes were heated and cooled in a stream of dry air, in like manner as they had been treated with other gases. The occluded air given out in one hour amounted in two different experiments to 1·15 and 0·95 cub. centim. respectively. The gas of the second experiment gave

0·82 cub. centim. Nitrogen . = 86·3
0·08 ,, ,, Carbonic acid = 8·4
0·05 ,, ,, Oxygen . . = 5·3
0·95 100·0

The whole occluded air amounts to 0·2 volume of the gold, and is principally *nitrogen.* The indifference of gold to oxygen is remarkable, and contrasts with the power of silver to occlude the same gas.

Silver.

1. Fine silver, in the form of wire, 2 millims. in diameter, with its surface duly purified, was first heated alone in the porcelain tube, and then exhausted of gas by the Sprengel tube in the usual way. The natural gas derived from this metal was small in quantity, and it appeared to come off almost entirely in one hour. The silver wire weighed 108·8 grms., and had a volume of 10·37 cub. centims., taking the specific gravity of pure silver as 10·49. The gas extracted amounted to

2·2 cub. centims. in thirty minutes.
0·8 ,, ,, ,,
3·0 ,, ,, in one hour.

The gas consisted of

2·4 cub. centims. Carbonic acid.
0·6 ,, ,, Carbonic oxide.
3·0

Silver wire therefore appeared to hold occluded 0·289 volume of gas, principally carbonic acid. There is reason, however, to suppose that the occluded gas may really be oxygen, and that the latter was converted into carbonic acid at the temperature of extrication, by a trace of carbon existing in the fine silver.

2. The same quantity of silver wire was now charged with hydrogen, by being heated to redness and afterwards cooled slowly in that gas. The gas extricated amounted to

2·3 cub. centims. in forty-five minutes.
0·2 ,, ,, in fifteen minutes.
2·5 ,, ,, in one hour.

The gas consisted of

2·2 cub. centims. Hydrogen.
0·3 „ „ Nitrogen, &c.
2·5

The fine silver had therefore occluded 0·211 volume of hydrogen. The metal acquired a beautiful frosted appearance on the surface; and by repeated heating it became highly crystalline and brittle.

3. The same portion of silver was now charged with oxygen. The occluded gas given off amounted to

7·5 cub. centims. in thirty minutes.
0·3 „ „ „
7·8 „ „ in one hour.

The gas consisted of

7·6 cub. centims. Oxygen.
0·2 „ „ Nitrogen, &c.
7·8

The silver therefore held occluded 0·745 volume of oxygen. This gas, like the hydrogen in platinum, was permanently fixed in the metal at all temperatures below an incipient red heat. It did not tarnish the bright metallic surface of the silver, or produce any appearance suggestive of the oxidation of a metal.

4. The same portion of silver, after being dissolved in acid, precipitated as chloride, and reduced again, was exposed to atmospheric air at a red heat, and afterwards exhausted. The gas given off amounted to

5·56 cub. centims. in fifteen minutes.
0·30 „ „ „
5·86

Of this gas 5·56 cub. centims., or nearly the whole, proved to be oxygen gas; or the silver held occluded 0·545 volume of oxygen. This silver had been purified from the chloride, and it contained no trace of copper.

When silver, of British Standard (that is, containing 7·5 per cent. of copper), is exposed to air or oxygen at a low red heat, the silver becomes almost black on the surface from oxidation of the copper. Silver wire in this blackened state gave off several volumes of oxygen under the action of heat and a vacuum. Much of the superficial oxide disappeared at the same time. It appeared as if the operation tended to the reduction of the superficial oxide of copper, oxygen being liberated, and the copper absorbed by the mass of silver.

5. A specimen of silver reduced from the oxide, in the form of sponge, which was considered pure, but was not analyzed, occluded 6·15, 8·05, and 7·47 volumes of oxygen, in successive experiments, without any visible tarnish of the surface. Can the attraction

or affinity of silver for oxygen, which enables the pure metal to occlude that gas, be enhanced by the presence of a mere trace of some positive metal like copper?

6. The same specimen of fritted silver was found to occlude, in successive experiments,

0·907	vol.	Hydrogen.
0·938	„	„
0·486	„	Carbonic acid.
0·545	„	„ „
0·156	„	Carbonic oxide.

Hydrogen and carbonic acid, as well as oxygen, appear to be taken up in larger proportion by this silver than by the former specimen of the same metal.

7. Of pure silver highly laminated, 500 leaves, weighing 12·5 grms., were exposed to air at a red heat, and thereafter exhausted at the same temperature. The silver (1 vol.) gave up 1·37 volume of oxygen, 0·20 volume of nitrogen, and 0·04 volume of carbonic acid.

It appears that silver has a relation to oxygen similar to that exhibited by platinum, palladium, and iron to hydrogen. The power of silver and of litharge in a state of fusion to absorb oxygen, and to allow that gas to escape on solidification, may be connected with the observed capacity of the colloid metal, softened by heat, to absorb the same gas, although to a less extent.

Iron.

The penetration of iron by hydrogen is demonstrated as clearly by MM. Deville and Troost as that of platinum. A thin tube of cast steel, 3 or 4 millims. in thickness, already enclosing hydrogen gas in its cavity, was surrounded by air or by nitrogen gas circulating in an annular space between the steel tube mentioned and a wider external porcelain tube. In the absence of any visible pores in the steel, hydrogen made its way through the substance of the metal, and escaped into the annular space as soon as the system of tubes was exposed to a red heat. A nearly if not entirely complete vacuum was formed within the iron tube*. In another modification of the experiment, carbonic oxide from an uncertain source appeared within the iron tube, particularly when the temperature was most elevated†.

Wrought iron, in the form of thin wire (No. 23), about 0·4 millim. in diameter, first carefully cleaned with caustic alkali and water, was heated alone in the porcelain tube exhausted of air, for the purpose of eliminating any natural gases.

1. Of the iron wire referred to, 46 grms., with a volume of 5·9 cub. centims., the specific gravity of the metal being taken at 7·8, were heated by the open combustion-furnace. Gas came off freely at a red heat,—

(1) In fifteen minutes, 15·6 cub. centims., containing 3·5 cub. centims. carbonic acid, or 22·4 per cent.

---

* Comptes Rendus, t. lvii. p. 965 (1863).

† Ib. t. lix. p. 102 (1864).

(2) In fifteen minutes, 7·17 cub. centims., containing 0·52 cub. centim. or 7·2 per cent. of carbonic acid. The gas of this and the following stages of observation now burnt with a blue flame, and was principally carbonic oxide.

(3) In thirty minutes, 10·4 cub. centims., of which 6·86 cub. centims. were carbonic oxide.

(4) In thirty minutes, 8·16 cub. centims., of which 0·12, or 1·4 per cent., was carbonic acid.

(5) In thirty minutes, 5·52 cub. centims., of which 0·03 was carbonic acid—that is, 0·5 per cent.

Hence 46 grms. of wrought iron have in two hours given off 46·85 cub. centims. of gas, measured at about 15° C.; or 1 volume of iron has discharged 7·94 volumes of gas, of which about two-thirds was carbonic oxide; and the metal does not appear to be yet quite exhausted. Iron is a metal not unlikely to contain small quantities of carbon and oxygen, both in chemical union with iron; and the gas extricated may partly be due to a reaction of these elements upon each other at a red heat.

2. In another similar experiment upon 32 grms. of clean iron wire (No. 21), measuring 4·1 cub. centims., the iron was heated in a small glass tube, to exclude the idea of the conceivable permeability of the porcelain tube. The iron gave off gas at a pretty uniform rate, which amounted in an hour to 29·8 cub. centims., of which 4·44 cub. centims. were carbonic acid, and the remainder principally carbonic oxide, with hydrogen and a trace of a hydro-carburet. Here the iron wire gave off 7·27 volumes of gas.

3. In a third experiment on thin iron wire (No. 23), the extrication of the natural gases at a red heat was pushed to a greater degree of exhaustion. The weight of the iron was 39 grms., and its volume 5 cub. centims. In the first and second hour the gas collected was 45 cub. centims.; in the third hour 10·85 cub. centims.; in the fourth and fifth hours 5·65 cub. centims.; in the sixth hour 0·9 cub. centim., and in the seventh hour 0·7 cub. centim. The iron appears to be now nearly exhausted, after the extrication of 63·1 cub. centims., or 12·55 volumes of gas.

It is evident that iron cannot be safely dealt with in experiments upon the permeation or upon the absorption of gases, till these gases, whether self-produced or preexisting, are first extricated from the metal. The carbonic oxide observed in the tube experiments of M. DEVILLE may have been derived from the same source*.

4. To observe the absorption of hydrogen, the mass of exhausted iron wire remaining after the last experiment was heated to redness, and cooled gradually in the same gas. The metal was afterwards freely exposed to air (as usual) to get rid of any loosely attached hydrogen. Now exhausted again by the Sprengel pump at a low red heat, the iron gave 2·5 cub. centims. of gas in one hour, but the greater portion in the first ten minutes, consisting of

---

* The gases which escape from cast iron in a state of fusion have been examined by M. L. CAILLETET. They appear to contain from 49 to 58 per cent. of carbonic oxide, 34 to 39 of hydrogen, and 8 to 12 of nitrogen.—Comptes Rendus, t. lxi. p. 850 (1865).

2·3	cub. centims.	Hydrogen.
0·2	,, ,,	Carbonic oxide, &c.
2·5		

The iron appears therefore to be capable of holding 0·46 volume of hydrogen. The wire became white, like galvanized iron. This was confirmed in a second observation, a thicker wire holding 0·42 vol. hydrogen.

5. The same specimen of iron was now charged with carbonic oxide gas, in the manner it had previously been charged with hydrogen. It was also freely exposed to air. The iron wire remained soft, was not capable of becoming hard when heated red-hot and suddenly cooled, and was not altered in aspect or in solubility in acids. The gas extricated by the air-exhauster amounted to

9·45	cub. centims.	in 13 minutes.
2·43	,, ,,	5 ,,
8·05	,, ,,	42 ,,
3·15	,, ,,	60 ,,
23·08	,, ,,	in two hours.

Of this gas 20·76 cub. centims. proved to be carbonic oxide. *Pure iron, then, is capable of taking up at a low red heat, and holding when cold,* 4·15 *volumes of carbonic oxide gas.* This fact was confirmed in various other experiments. It explains partly, if not entirely, the abundance of carbonic oxide observed among the natural gases of iron in experiments 1, 2, and 3. In the course of its preparation wrought iron may be supposed to occlude six or eight times its volume of carbonic oxide gas, which is carried about ever after. How the qualities of iron are affected by the presence of such a substance, no way metallic in its characters, locked up in so strange a way, but capable of reappearing, under the influence of heat, at any time, with the elastic tension of a gas, is a subject which metallurgists may find worthy of investigation.

The relations of the metal iron to carbonic oxide gas appear to be altogether peculiar. They cannot fail to have a bearing upon the important process of *acieration.* The intervention of carbonic oxide in the usual process of the cementation of iron with charcoal, long recognized by accurate observers, may be said now to be placed beyond all doubt by the recent beautiful research of M. MARGUERITTE[*]. Hitherto the decomposing action of the iron upon carbonic oxide has been supposed to be exercised only at the external surface of the metal. A surface-particle of the iron has been supposed to assume one half of the carbon belonging to an equivalent of carbonic oxide ($C_2 O_2$), while the remaining elements diffused away into the air as carbonic acid ($C O_2$), to reacquire carbon from the charcoal placed near, and to become capable of repeating the original action. It is now seen that such a process need not be confined to the surface of the iron bar, but may occur throughout the substance of the metal, in consequence of the prior penetration of the metal by carbonic oxide. The direct contact and action of carbon (in the form either of diamond or charcoal) upon iron is allowed to produce cast iron and not steel. It appears that the diffused action of carbonic oxide is the proper means of distributing the carbon throughout the mass of iron. The blistering of the bar appears to testify to the necessary production and evolution of carbonic acid, owing to the decomposition of the carbonic oxide in the interior of the bar.

---

[*] Annales de Chimie, &c., 4 sér. t. vi., 1865.

The inquiry suggests itself whether acieration would not be promoted by alternation of temperature frequently repeated. The lowest red heat, or a temperature even lower, appears to be most favourable to the absorption of carbonic oxide by iron, or for impregnating the metal with that gas; while a much higher temperature appears to be required to enable the metal to decompose carbonic oxide, to appropriate the carbon, and become steel. The action of a high temperature is made very clear by M. MARGUERITTE. The process of acieration, it seems then, should be divided into two distinct stages, conducted at very different temperatures,—the first to introduce carbonic oxide into the iron, and the second to decompose the carbonic oxide so introduced. The carbonic oxide once safely occluded by the iron, the metal might even be cooled and preserved in the air, the second heating being postponed for any length of time. Such alternations of temperature are not unlikely to occur by accident during the usual long process of cementation; but they might be properly regulated with advantage, and the process may admit of being abridged in point of time.

Antimony, as a highly crystallizable metal, was exposed to hydrogen gas both above and below the point of fusion of the metal, and afterwards submitted to exhaustion in the usual manner. No hydrogen was extricated.

XIX. *Results of the Magnetic Observations at the Kew Observatory.*—No. III.

By Lieut.-General Edward Sabine, *R.A.*, *President of the Royal Society.*

Received June 21,—Read June 21, 1866.

§ 9. *Lunar-diurnal Variation of the three Magnetic Elements.*

The recognition of a cosmical origin of some of the variations of terrestrial magnetism has made it desirable to employ in magnetic observatories apparatus of a more exact and dependable character, and methods of dealing with the results thus obtained of a more close and rigorous description, than were previously thought requisite. The present communication is directed to the discussion of the Lunar-diurnal Variation of the three magnetic elements shown by the instruments and methods adopted at the Kew Observatory, commencing in 1858, and continued as far as the reductions have at present proceeded, viz. to the close of 1864. It has the double purpose, first, of making known the systematic and highly satisfactory character of the results which have been already obtained; and, second, of acting in some measure as a guide, and certainly as an encouragement, to the several establishments at home and abroad which have adopted the Kew System of magnetic investigation.

The instruments employed for the determination of the lunar-diurnal variation furnish a continuous photographic registry of the changes in the direction of a magnet whose motion is limited to a horizontal plane, and in the amounts of the horizontal and vertical components of the force acting on a freely suspended magnet. The photograms which record these changes are submitted to a very careful and exact process, by which the variations from a permanent zero, of the horizontal magnetic direction, and of the amounts of the horizontal and vertical components of the Force, are measured and tabulated at twenty-four equidistant intervals of an astronomical solar day. The accuracy of the tabulations is checked by a repetition of the process of measurement by different persons, and by a reexamination in cases of discrepancy. The proportion of failures in the hourly records from any or from all causes whatsoever is very small—less in fact than 1 per cent. throughout the whole period. The subjoined Table (No. I.) shows that of 175344 positions which should have been recorded, there were only 1497 failures, of which 103 were occasioned by the employment of the instruments in other experimental processes. It must be remembered also that the period under notice is that of the *commencement* of the record, when experience has to be gained, and the causes of accidental failures have to be remedied.

The positions thus measured from the photograms at every hour of astronomical time, and entered in monthly tables, were then subjected to the usual processes, first, of computing the monthly means for each of the twenty-four hours in every month; and second, of marking (for subsequent exclusion) every hourly position which differed from the mean of the same hour in the same month, not less than a certain specified and definite amount; such difference being regarded as evidence of the presence of a magnetic disturbance. The amount of difference thus adopted as a criterion (known commonly by the name of "the separating value") was constant throughout; being 0·150 of a scale-division in the Declination, and 0·106 of a scale-division in each of the other elements; equivalent to 3'·3 of arc in the Declination, ·00109 part of the horizontal force at Kew, and ·000269 part of the vertical force at Kew. The number of hourly positions thus separated was, in the Declination 10271, or about 1 in 5·9 of the whole body; in the horizontal force 11·747, or about 1 in 5·1 of the whole; and in the vertical force 13·562, or about 1 in 3·8 of the whole. The record of the hourly positions, exclusive of those thus separated, was then rearranged and rewritten in *Lunar Tables*, according to the *Lunar hours* to which each position most nearly corresponded; and from these the mean variation in each lunar hour in each year was derived, as shown in the subsequent Tables, Nos. II., III., and IV.

The tabulation from the photograms and the subsequent calculations were executed at the Magnetic Office at Woolwich, under the superintendence of Mr. JOHN MAGRATH.

I have been thus particular in stating the processes which the photographic records have undergone, first, because that which forms the subject matter of the investigation, viz. the moon's action on the magnetism of the globe, is measurable only by very minute quantities, and requires consequently peculiar care and suitable arrangements for its satisfactory detection and determination; and secondly, because the results, now submitted to the Royal Society, present a variation which, small as it is in amount, is far too regular and too systematic to be ascribed to accidental causes, and affords a strong indication of the existence of a general law, the complete development of which has yet to be looked for from the extension of similar investigations in other localities. A great encouragement to the prosecution of the research is supplied by the remarkable correspondence of the phenomena of the lunar-diurnal variation at Kew, as now made known to us, with those at Hobarton, shown by the results of the observations at that Observatory between the years 1843 and 1848. The general aspect of the variation produced by the moon's influence at the two stations is the same, viz. a double progression in every twenty-four lunar hours, producing extreme deflections of the same character at opposite points of the moon's diurnal course; the turning-points of the variation taking place nearly at the same lunar hour at each of the two stations, and the amounts of the variation being approximately the same at both. The stations (Kew and Hobarton) being in opposite magnetic hemispheres, we might naturally expect what we actually find to be the case, that the lunar hours of the maxima of *Easterly* deflection in the one hemisphere are those of *Westerly* deflection in the other hemisphere, and *vice versâ*; and that the lunar hours of the maxima and minima of the north Dip and of the northern Total Force at Kew are the same as those of the maxima and minima of south Dip and of the southern

Total Force at Hobarton. The approximate accordance of the numerical values of the lunar influence at the two stations, and in each of the three elements, is also the more remarkable when we take into view the shortness of the time during which the investigation has as yet been prosecuted, and the minuteness of the quantities which are involved—measured as they are by a few seconds of arc in the Declination and Inclination, and by millionth parts of the terrestrial magnetic force. Such an accordance cannot be viewed otherwise than as a great encouragement to the continuance of the research where it is already in progress, and to its adoption elsewhere.

The conclusions in regard to the Declination are those which will perhaps be generally regarded as entitled to principal consideration, inasmuch as their derivation is much more direct than in the cases either of the Inclination or of the Total Force. To this it may be added that, in comparing the declination-phenomena at Kew and Hobarton, we have the advantage of a somewhat larger series of observations than is the case either in the Inclination or in the Total Force, as the hourly observations of the Declination at Hobarton in 1841 and 1842 are available for the purpose, in addition to those of the subsequent years 1843–1848; making together eight years of the Declination, whilst we have only six years of either the Horizontal or the Vertical Force. In all cases, however, and whether from Kew, Hobarton, or elsewhere, the numerical values which we may derive in regard to the lunar influence can only be regarded as approximations; and as indicating generally what we may expect will be accomplished by a further perseverance, rather than as preferring a claim to present or immediate *precision.* With this reservation we may view the facts regarding the moon's influence on the magnetic declination at Kew and Hobarton as placing beyond doubt the existence, at this particular epoch in the great cycle of the variations of the terrestrial magnetism, of a lunar-diurnal variation which has two equal or very nearly equal progressions, both in time and in amount; producing consequently two easterly and two westerly maxima of deflection in every lunar day, with four nodal epochs, occurring also at nearly equal intervals of lunar time, in which the direction of the magnet due to other causes is undisturbed by the moon's influence. The lunar hours of extreme deflection at Kew and Hobarton are 1, 7, 13, and 19; 1 and 13 being the westerly extremes at Kew and easterly at Hobarton; the nodal hours, or those in which the lunar influence is inoperative in producing deflection, are, as nearly as can be judged, strictly intermediate between the times of extreme deflection; viz., between 4 and 5, 10 and 11, 16 and 17, 22 and 23 hours. The amounts of the extreme deflections, measured by the mean of all the observations hitherto, are at Kew, westerly, $11''\cdot1$ at 1 hour, $9''\cdot4$ at 13 hours; easterly, $11''\cdot6$ at 7 hours, $10''\cdot8$ at 19 hours: at Hobarton, easterly, $8''\cdot4$ at 1 hour, $9''\cdot1$ at 13 hours; westerly, $7''\cdot3$ at 7 hours, and $9''\cdot1$ at 19 hours. The antagonistic terrestrial magnetic force by which the deflecting action of the moon on the horizontal magnet is opposed, is (approximately) 4·5 at Hobarton, and 3·8 at Kew, expressed in British units.

If we now extend this examination to other stations in the middle latitudes where the same methods of investigation have been pursued, though with series of observations of shorter continuance, we find an approximation to the results at Kew and Hobarton far too close to be accidental. Everywhere there is evidence of a similar double progression in the lunar day with branches of nearly equal duration. The extreme deflections which we have noted as occurring at Kew and Hobarton at the lunar hours of 1 and 13 (easterly at Kew and westerly at Hobarton), are recorded as occurring at Toronto at 0^h and 12^h, at Philadelphia at 1^h and 13^h, and at Pekin at 23^h and 11^h, all being maxima of easterly deflection; and at the Cape of Good Hope (a *westerly* maximum, as the Cape is in the southern hemisphere) at 23^h and 11^h. In like manner the hours which characterize the opposite extremes at Kew and Toronto to those just noticed, viz., the westerly at Kew and easterly at Hobarton, which are at 7^h and 19^h, are recorded as occurring at Toronto at 6^h and 18^h, at Philadelphia at 7^h and 19^h, at Pekin at $5^h{\cdot}5$ and $17^h{\cdot}5$, and at the Cape of Good Hope at $5^h{\cdot}5$ and $17^h{\cdot}5$.

Some difference, in the time of the occurrence of a particular phase of the variation, as well as in its amount, we should be prepared to find in different localities, due to differences in their position on the surface of the magnetic sphere; but with this allowance there is a systematic consistency in the particulars which have been cited, which, even in this, the infancy of the inquiry, promises to conduct those who will pursue it to the recognition of one of those laws of general application which characterize the operation of great cosmical forces.

A corresponding accordance in the phenomena of the lunar influence on the Inclination and on the Total Force might easily be shown, even from the very brief record which we as yet possess from the very few stations at which the phenomena have been made the objects of investigation, carried on with suitable instruments and with suitable methods of reduction. The conclusions from them are indeed somewhat less precise than in the case of the Declination, because the conditions of the problem are necessarily more complex; but they have the same general character and bearing in all material respects; and enough has already been stated to establish the general fact of the existence and systematic action of the moon's magnetic influence at the surface of our globe, and to show that its phenomena are quite within the reach of properly directed research; and that they are assuredly well worthy of the attention of those who occupy themselves in the pursuits of inductive philosophy.

To establish on a satisfactory basis the existence of a difference in the amount of the lunar-diurnal variation at the times when the moon is nearest to or furthest from the earth, would probably require many more years of observation than have hitherto been given to the subject at Kew. But it may not be superfluous to state that in the Vertical Force, which is the only one of the elements in which the extreme deflections at the turning hours on the two days preceding and the two days subsequent to the epochs of perigee and apogee have hitherto been separately examined, the deflections are decidedly greater in their mean amount in perigee than in apogee; which is so far encouraging towards a continuance of the examination in future years.

Semiannual Inequality.—In the elaborate and very valuable discussion of the magnetic observations at Girard College, Philadelphia, 1840–1845, contained in the thirteenth volume of the 'Smithsonian Contributions to Knowledge' (1863), Dr. Alexander Dallas Bache, For. Mem. R.S., announced the existence of a semiannual inequality in the lunar-diurnal variation of the Declination as shown in two particulars, (1) that the amplitudes of the deflections both to the east and to the west, and in both the 12-hourly divisions of the (lunar) diurnal variation, are less in the six months from October to March than in the six months from April to September; and (2) that the lunar hours at which the deflections pass through the zero are earlier by more than an hour in October to March than in April to September (Smithsonian Contributions, vol. xiii. part 3, pp. 11–13). In the case of the Horizontal Force, Dr. Bache finds a similar semiannual inequality in the hours of maxima and minima, but in respect to their *amounts* he remarks that the range in April to September is but *slightly greater* than that in October to March, the difference being by no means so marked a feature as in the Declination (Smithsonian Contributions, vol. xiii. part 6, p. 72). The lunar-diurnal variation of the Vertical Force at Girard College does not appear to have been examined.

The above results were derived by a treatment of the observations conducted according to the same general principles, in regard to the separation of the larger disturbances, which had been previously introduced by myself in the discussion of the British Colonial magnetic observations.

Following Dr. Bache's example in this particular investigation, I directed Mr. Magrath, who is charged with the superintendence (under myself) of the reduction of the magnetic observations at the Woolwich Office, to separate the lunar-diurnal effects at Kew into two portions, one of which should contain the months from April to September inclusive, and the other the months from October to March inclusive, being the division of the year adopted by Dr. Bache. The subjoined Table (No. V.) exhibits the *semiannual* as well as the annual means of the lunar-diurnal variation of the Declination at Kew taken from the photograms commencing January the 1st, 1858, and terminating December 31, 1864. The Table is divided into two portions solely for convenience in printing.

Table V.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Declination at Kew.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
Semiannual Means ...	April to September..	−0′·23	−0′·25	−0′·19	−0′·06	+0′·01	+0′·08	+0′·20	+0′·29	+0′·17	+0′·07	+0′·04	−0′·12
	October to March ...	−0·03	−0·13	−0·18	−0·06	−0·15	−0·04	+0·04	+0·09	+0·15	+0·09	+0·02	+0·01
Annual Means		−0·13	−0·19	−0·18	−0·06	−0·07	+0·02	+0·12	+0·19	+0·16	+0·08	+0·03	−0·05

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
Semiannual Means ...	April to September..	−0′·18	−0′·19	−0′·15	−0′·05	+0′·06	+0′·17	+0′·18	+0′·20	+0′·15	+0′·11	−0′·04	−0′·15
	October to March ...	−0·06	−0·12	−0·11	−0·07	0·00	+0·01	+0·09	+0·16	+0·17	+0·11	+0·11	+0·07
Annual Means		−0·12	−0·16	−0·13	−0·06	+0·03	+0·09	+0·14	+0·18	+0·16	+0·11	+0·03	−0·04

It is obvious on an inspection of this Table that the deflections of the Declination at Kew, both those that are easterly and those that are westerly, attain a greater amplitude in the months April to September than in the months October to March, and that the extremes appear to be reached at a somewhat *earlier* hour at Kew in the April to September than in the October to March portion of the year. The first of these indications is in accordance with the results at Philadelphia; the second is not so. With respect to the first, viz., the greater amplitudes in the months April to September, if we take the hours 22 to 3 and 10 to 15 as those of the − variation, and the hours 4 to 9 and 16 to 21 as those of the + variation for both half years, we have the sums (disregarding their half-yearly signs) of the semiannual monthly means for April to September 2′·50, and for October to March 1′·23. And if, retaining the hours 22 to 3, 4 to 9, 10 to 15, and 16 to 21 as the most suitable division in the April to September half year, we adopt the division of 23 to 4, 5 to 10, 11 to 16, and 17 to 22 as possibly preferable for the October to March half year, we have the sums (disregarding their signs) of the semiannual monthly means, 2′·50 in April to September and 1′·83 in October to March. In both arrangements the deflections are considerably greater in the April to September half year than in the October to March half year.

The Kew results appear therefore to be confirmatory of the Philadelphia results as to the greater amplitude of the lunar-diurnal deflections in April to September; but in regard to a slight priority in the hours of occurrence of the maxima and minima in either half year, the inference from the observations at Kew would be, as far as it goes, dissimilar to that deduced by Dr. BACHE from the observations at Philadelphia.

Such being the case, it appeared the more desirable to make a similar examination of the lunar-diurnal variation of the Declination at a station (Hobarton) in the opposite, *i. e.* in the southern hemisphere, from whence we have nearly eight years of hourly eye-observations, viz. from January 1, 1841 to September 30, 1848. Table VI. exhibits the semiannual and annual means of the lunar-diurnal variation of the Declination at Hobarton arranged as at Kew and Philadelphia.

TABLE VI.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Declination at Hobarton.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
Semiannual Means ...	April to September ...	0′·00	−0′·03	+0′·06	+0′·03	+0′·07	−0′·01	−0′·09	−0′·02	−0′·01	+0′·03	0′·00	+0′·08
	October to March......	+0·34	+0·40	+0·30	+0·25	+0·11	−0·10	−0·21	−0·32	−0·30	−0·20	−0·06	+0·05
Annual Means		+0·17	+0·18	+0·18	+0·14	+0·09	−0·05	−0·15	−0·17	−0·15	−0·08	−0·03	+0·07

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
Semiannual Means ...	April to September....	+0′·07	+0′·12	+0′·13	+0′·12	+0′·12	+0′·03	−0′·02	−0′·09	−0′·14	−0′·16	−0′·06	−0′·08
	October to March......	+0·17	+0·36	+0·29	+0·14	+0·07	−0·11	−0·31	−0·38	−0·32	−0·19	−0·01	+0·18
Annual Means		+0·12	+0·24	+0·21	+0·13	+0·09	−0·04	−0·16	−0·24	−0·23	−0·18	−0·04	+0·05

At Hobarton the results appear to be quite as consistent and systematic as those at Kew or at Philadelphia, whilst in respect to the period of the year when the amplitudes of the deflections are greatest, they present the phenomena in the reversed order, October to March taking the position which at Kew and Philadelphia characterizes the April to September half year. If we take the hours 0 to 5, 12 to 17 as those of + deflections, and 6 to 11, 18 to 23 as those of − deflections for both the half years at Hobarton, we have the sums (disregarding their signs) of the semiannual monthly means for October to March 4′·29, and for April to September 1′·27; or if 23 to 4, 5 to 10, 11 to 16, 17 to 22 be taken, as possibly a preferable arrangement for the half year October to March (retaining as before 0 to 5, 6 to 11, 12 to 17, and 18 to 23 for the months April to September), we have the sum 5′·05 for October to March against 1′·27 for April to September. Under either arrangement the disparity is considerable, and appears decisive in favour of regarding October to March as the half year of greatest deflection in the lunar-diurnal variation at Hobarton. October to March is also the season of the earlier occurrence of the maxima and minima: in both the presumed half-yearly characteristics, therefore, the Declination at Hobarton, in the southern hemisphere, presents the opposite features to the Declination at Kew in the northern hemisphere.

I have added in Tables VII., VIII., IX. and X., at the close of this communication, the annual and semiannual means of the lunar-diurnal variation of the Inclination and of the Total Force at Kew and at Hobarton, although the number of years from which these have been derived can hardly be considered sufficient to afford any secure foundation for more than very general inferences in these two elements. For more assured evidence we must await the continuation of the Kew Observations for the northern hemisphere, and the magnetic investigations about to be commenced at Melbourne for the southern hemisphere.

In the meantime what is most worthy of our consideration is, that all the tables (in the separate half years as well as in the whole year, and in all elements and all localities) concur in the manifestation of that which is the great and distinctive characteristic of the lunar-diurnal variation, viz. a double fluctuation in the twenty-four lunar hours in equal or nearly equal divisions. It is this feature which must chiefly press itself on the attention of those who would address themselves to the solution of the somewhat difficult problem of the true theory of the moon's influence on the magnetism of the earth. May it not be possible that this peculiar feature may be connected with the duplex system of the terrestrial magnetism?

TABLE I.—Synopsis of the number of Hourly Positions tabulated from the Magnetic Photographs at Kew in the Years from 1858 to 1864 inclusive.

Magnetic elements.	Years.	Actual number of hours.	Actual number of re-corded positions.	Interruption by other experimental inquiries.			Failures, and their causes.											Sums of recorded positions and failures.
				Exami-nation of scale-co-efficient.	Instru-mental adjust-ments.	Presence of other magnets.	Lamp out.	Clock stopped.	Clock line broken.	Cylinder stopped.	Glass chimney smoked.	No zero-line.	No trace.	Curve off the paper.	Curve no begin-ning or end.	Omitted. *	Total failures from all causes.	
Declina-tion.	1858.	8760	8618	......	......	12	16	4	......	......	......	......	110	......	......	......	142	8760
	1859.	8760	8701	3	......	......	......	12	......	......	......	......	44	......	......	......	59	8760
	1860.	8784	8720	2	......	......	......	20	......	......	......	......	40	......	......	2	64	8784
	1861.	8760	8692	8	......	......	......	16	......	......	......	......	20	......	24	......	68	8760
	1862.	8760	8693	4	......	......	......	8	......	22	......	......	29	......	......	4	67	8760
	1863.	8760	8743	6	......	......	......	4	......	......	......	......	6	1	......	......	17	8760
	1864.	8784	8744	5	1	3	10	2	8	......	......	......	7	4	......	......	40	8784
	Total ...	61368	60911	28	1	15	26	66	8	22	......	......	256	5	24	6	457	61368
Horizontal Force.	1858.	8760	8632	......	7	......	33	5	......	......	......	......	74	......	......	9	128	8760
	1859.	8760	8662	3	......	......	33	5	......	......	......	18	37	......	......	2	98	8760
	1860.	8784	8672	......	......	......	......	18	......	......	10	......	84	......	......	......	112	8784
	1861.	8760	8716	3	1	......	......	16	......	......	......	......	24	......	......	......	44	8760
	1862.	8760	8693	2	......	......	......	8	......	......	......	......	57	......	......	......	67	8760
	1863.	8760	8689	4	......	3	......	4	......	......	......	48	11	......	......	1	71	8760
	1864.	8784	8738	2	......	3	10	2	8	......	......	......	19	......	......	2	46	8784
	Total ...	61368	60802	14	8	6	76	58	8	......	10	66	306	......	......	14	566	61368
Vertical Force.	1859.	8760	8650	......	25	2	4	12	......	......	......	5	61	......	......	1	110	8760
	1860.	8784	8618	5	......	......	21	18	1	......	......	......	118	1	......	2	166	8784
	1861.	8760	8704	1	......	......	......	15	......	......	......	24	16	......	......	......	56	8760
	1862.	8760	8725	2	1	......	......	6	2	......	......	......	20	1	......	3	35	8760
	1863.	8760	8690	2	......	......	......	3	......	......	......	48	13	1	......	3	70	8760
	1864.	8784	8747	4	......	......	10	2	8	......	......	......	13	......	......	......	37	8784
	Total ...	52608	52134	14	26	2	35	56	11	......	......	77	241	3	......	9	474	52608
General Total...		175344	173847	56	35	23	137	180	27	22	10	143	803	8	24	29	1497	175344

* The term "omitted" applies to cases wherein the photograms were marked by a red line drawn over a portion of the curve with the direction "omit." These markings were made by Mr. CHARLES CHAMBERS (now in India), under whose superintendence the photograms were prepared. In all the cases so marked there were slight irregularities noticeable in the traces, due possibly to the presence of visitors in the magnetometer room, who may have had keys or knives in their pockets. But whether from these or other causes the hourly positions thus omitted amount only to 29 in number in the three elements in the seven years.

TABLE II.—Declination. Lunar-diurnal Variation in Seconds of Arc.

Lunar hours.	Years ending December 31.							Means.	Lunar hours.
	1858.	1859.	1860.	1861.	1862.	1863.	1864.		
0	w. 6″·0	E. 0″·6	w. 12″ 6	w. 5″·4	w. 7″·8	w. 9″·0	w. 14″·4	w. 7″·8	0
1	w. 14·4	w. 7·2	w. 12·6	w. 6·0	w. 6·6	w. 17·4	w. 13·2	w. 11·1	1
2	w. 10·8	w. 9·6	w. 5·4	w. 7·2	w. 9·0	w. 12·0	w. 21·0	w. 10·7	2
3	w. 7·8	w. 4·2	w. 3·0	E. 2·4	E 2·4	w. 6·6	w. 7·8	w. 3·5	3
4	w. 3·0	w. 4·2	w. 2·4	E. 4·2	E. 2·4	w. 6·6	w. 19·8	w. 4·2	4
5	E. 5·4	w. 6·6	E. 5·4	E. 6·6	E. 9·0	w. 4·2	w. 6·6	E. 1·3	5
6	E. 12·0	E. 1·2	E. 3·0	E. 14·4	E. 14·4	w. 2·4	E. 7·8	E. 7·2	6
7	E. 9·0	E. 4·2	E. 9·6	E. 16·2	E. 17·4	E. 15·6	E. 9·0	E. 11·6	7
8	E. 9·6	E. 8·4	E. 7·8	E. 6·6	E. 14 4	E. 15·6	E. 5·4	E. 9·7	8
9	E. 7·2	E. 6·6	w. 0·9	w. 1·2	E. 12·0	E. 7·8	E. 2·4	E. 4·8	9
10	E. 3·0	E. 7·2	w. 1·8	w. 6·6	w. 2·4	E. 7·8	E. 5·4	E. 1·8	10
11	w. 3·6	w. 1·2	w. 4·2	w. 10·8	w. 7·8	E. 6·6	0·0	w. 3·0	11
12	w. 4·8	w. 9·0	w. 18·0	w. 8·4	w. 7·8	0·0	w. 4·2	w. 7·5	12
13	w. 3·0	w. 13·2	w. 15·0	w. 13·2	w. 12·0	w. 5·4	w. 4·2	w. 9·4	13
14	w. 3·0	w. 8·4	w. 9·6	w. 10·8	w. 15·6	w. 10·8	E. 1·2	w. 8·1	14
15	w. 7·2	w. 3·6	E. 4·2	w. 8·4	w. 12·0	w. 2·4	E. 5·4	w. 3·4	15
16	E. 3·0	E. 3·6	E. 7·8	w. 6·6	w. 10·8	0·0	E. 14·4	E. 1·6	16
17	E. 7·8	E. 9·6	E. 13·8	w. 2·4	w. 4·2	E. 1·2	E. 12·0	E. 5·4	17
18	E. 7·8	E. 14·4	E 17·4	E. 3·0	0·0	E. 7·8	E. 5·4	E. 8·0	18
19	E. 4·8	E. 18·0	E. 15·0	E. 9·0	E. 2·4	E. 12·0	E. 14·4	E. 10·8	19
20	E. 3·0	E. 12·6	E. 6·0	E. 10·2	E. 12·0	E. 14·4	E. 9·0	E. 9·6	20
21	w. 2·4	E. 18·6	E. 2·4	E. 10·8	E. 7·8	E. 2·4	E. 7·8	E. 6·8	21
22	w. 7·8	E. 9·6	w. 3·0	E. 7·8	E. 5·4	E. 1·2	0·0	E. 1·9	22
23	w. 6·0	E. 5·4	w. 3·6	E. 0·6	w. 4·2	w. 1·2	w. 7·8	w. 2·4	23

TABLE III.—Horizontal Force. Lunar-diurnal Variation in parts of the Force at the Station.

Lunar hours.	Years ending December 31.							Means of the seven years.	Lunar hours.
	1858.	1859.	1860.	1861.	1862.	1863.	1864.		
0	+·000052	+·000039	+·000091	+·000033	+·000038	+·000087	+·000017	+·000051	0
1	+·000045	+·000080	+·000138	+·000067	+·000049	+·000098	+·000054	+·000076	1
2	+·000037	+·000075	+·000121	+·000080	+·000071	+·000085	+·000087	+·000079	2
3	+·000013	+·000103	+·000131	+·000055	+·000054	+·000040	+·000055	+·000064	3
4	+·000002	+·000091	+·000124	+·000022	+·000071	+·000026	+·000040	+·000054	4
5	—·000020	+·000076	+·000122	+·000029	+·000028	+·000028	+·000035	+·000043	5
6	—·000011	+·000020	+·000085	—·000023	—·000028	+·000056	—·000031	+·000010	6
7	—·000003	+·000010	+·000078	—·000061	—·000044	+·000001	—·000036	—·000008	7
8	—·000024	+·000018	+·000041	—·000063	+·000014	—·000009	—·000006	—·000004	8
9	—·000009	—·000023	+·000087	—·000118	—·000029	+·000024	—·000089	—·000022	9
10	—·000021	—·000032	+·000076	—·000060	+·000018	—·000008	—·000013	—·000006	10
11	—·000001	—·000031	+·000066	—·000047	+·000018	+·000060	+·000036	+·000014	11
12	+·000046	+·000015	+·000056	—·000024	+·000040	+·000083	+·000067	+·000040	12
13	+·000031	+·000025	+·000112	+·000022	+·000097	+·000073	+·000062	+·000060	13
14	—·000014	+·000050	+·000088	+·000013	+·000094	+·000123	+·000069	+·000060	14
15	+·000025	+·000033	+·000089	+·000032	+·000056	+·000079	+·000059	+·000053	15
16	+·000021	+·000054	+·000071	+·000049	+·000081	+·000058	+·000014	+·000050	16
17	+·000017	+·000034	+·000046	+·000042	+·000051	+·000017	—·000025	+·000026	17
18	+·000003	—·000033	—·000011	+·000027	·000000	+·000030	+·000029	+·000006	18
19	+·000018	·000000	+·000001	—·000025	—·000026	—·000019	+·000003	—·000007	19
20	—·000002	—·000034	+·000002	+·000013	—·000006	+·000011	—·000036	—·000007	20
21	—·000001	—·000010	—·000020	+·000043	—·000010	+·000017	—·000015	+·000001	21
22	—·000028	—·000021	+·000040	+·000012	+·000011	—·000010	+·000005	+·000001	22
23	+·000053	+·000027	+·000036	+·000010	+·000074	+·000042	+·000001	+·000035	23

The mean Horizontal Force at Kew is approximately 3·8 in British units.

TABLE IV.—Vertical Force. Lunar-diurnal Variation in parts of the Force at the Station.

Lunar hours.	Years ending December 31.						Means of the six years.	Lunar hours.
	1859.	1860.	1861.	1862.	1863.	1864.		
0	−·000019	−·000003	·000000	+·000017	−·000003	−·000025	−·000005	0
1	−·000008	+·000003	+·000001	+·000028	+·000011	−·000009	+·000004	1
2	−·000007	+·000008	+·000002	+·000030	+·000018	+·000003	+·000009	2
3	−·000006	+·000018	+·000017	+·000021	+·000015	−·000003	+·000010	3
4	−·000004	+·000008	+·000007	+·000020	+·000016	+·000006	+·000009	4
5	−·000012	·000000	−·000002	+·000016	+·000010	+·000005	+·000003	5
6	−·000013	+·000010	−·000008	+·000005	−·000001	−·000006	−·000002	6
7	−·000015	+·000001	−·000010	+·000004	−·000003	·000000	−·000004	7
8	−·000009	−·000006	−·000007	−·000001	−·000011	−·000006	−·000007	8
9	−·000017	−·000019	−·000018	−·000003	−·000012	+·000004	−·000011	9
10	−·000014	−·000004	−·000013	−·000004	−·000008	+·000006	−·000006	10
11	−·000004	−·000008	+·000008	+·000004	−·000005	+·000008	·000000	11
12	−·000005	−·000004	−·000011	+·000007	−·000005	+·000018	·000000	12
13	−·000005	−·000001	·000000	+·000004	−·000001	+·000012	+·000001	13
14	+·000001	+·000008	+·000002	+·000020	−·000004	+·000013	+·000007	14
15	+·000004	+·000020	+·000005	+·000021	·000000	+·000015	+·000011	15
16	+·000002	+·000003	·000000	+·000020	·000000	+·000014	+·000006	16
17	−·000001	·000000	+·000008	+·000021	−·000014	+·000024	+·000006	17
18	−·000006	−·000002	·000000	+·000011	−·000022	+·000007	−·000002	18
19	−·000018	−·000016	−·000002	+·000012	−·000033	+·000004	−·000009	19
20	−·000031	−·000015	−·000001	+·000012	−·000020	−·000006	−·000010	20
21	−·000034	−·000016	−·000013	−·000004	−·000033	−·000026	−·000021	21
22	−·000026	−·000018	−·000006	+·000004	−·000018	−·000023	−·000014	22
23	−·000021	−·000013	−·000007	+·000007	−·000012	−·000021	−·000011	23

The mean Vertical Force at Kew is approximately 9·5 in British units.

TABLE VII.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Inclination at Kew.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
Semiannual Means …	April to September …	−0′·09	−0′·10	−0′·09	−0′·07	−0′·07	−0′·04	+0′·01	+0′·02	+0′·03	+0′·02	0′·00	−0′·01
	October to March……	−0·04	−0·08	−0·07	−0·04	−0·03	−0·04	−0·03	0·00	−0·03	0·00	0·00	−0·02
Annual Means ………………………		−0·07	−0·09	−0·08	−0·06	−0·05	−0·04	−0·01	+0·01	0·00	+0·01	0·00	−0·02

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
Semiannual Means …	April to September …	−0′·06	−0′·11	−0′·08	−0′·09	−0′·07	−0′·01	+0′·02	+0′·01	+0′·01	−0′·03	−0′·01	−0′·06
	October to March……	−0·03	−0·03	−0·04	−0·01	−0·03	−0·04	−0·03	−0·02	0·00	−0·01	−0·02	−0·05
Annual Means ………………………		−0·05	−0·07	−0·06	−0·05	−0·05	−0·02	0·00	0·00	0·00	−0·02	−0·02	−0·05

TABLE VIII.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Total Force at Kew, in parts of the Total Force at the Station.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
		·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
Semiannual Means ...	April to September ...	+0006	+0020	+0026	+0027	+0020	+0018	+0004	+0003	−0000	−0005	−0003	+0006
	October to March	0000	+0012	+0013	+0010	+0011	0000	−0004	−0010	−0010	−0018	−0008	−0003
Annual Means		+0003	+0016	+0019	+0018	+0015	+0009	0000	−0004	−0005	−0012	−0005	+0002

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
		·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
Semiannual Means ...	April to September ...	+0015	+0021	+0022	+0028	+0027	+0016	+0001	−0001	−0006	−0016	−0011	−0001
	October to March	−0001	−0001	+0004	+0004	0000	+0002	0000	−0013	−0013	−0019	−0011	−0007
Annual Means		+0007	+0010	+0013	+0016	+0013	+0009	0000	−0007	−0010	−0018	−0011	−0004

TABLE IX.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Inclination at Hobarton.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
Semiannual Means ...	April to September..	+0′·04	+0′·01	−0′·01	−0′·01	−0′·03	−0′·01	0′·00	0′·00	+0′·02	+0′·01	−0′·02	0′·00
	October to March ...	+0·01	−0·02	−0·04	−0·04	−0·05	−0·01	−0·04	−0·03	+0·02	+0·02	+0·03	+0·03
Annual Means		+0·02	0·00	−0·02	−0·03	−0·04	−0·01	−0·02	−0·01	+0·02	+0·01	0·00	+0·01

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
Semiannual Means ...	April to September..	−0′·02	−0′·01	0′·00	−0′·02	−0′·03	0′·00	−0′·01	−0′·01	−0′·01	+0′·01	+0′·03	+0′·06
	October to March ...	+0·02	−0·01	−0·04	−0·03	−0·04	−0·03	−0·01	+0·02	+0·03	+0·06	+0·05	+0·02
Annual Means		0·00	−0·01	−0·02	−0·02	−0·04	−0·02	−0·01	0·00	+0·01	+0·03	+0·04	+0·04

TABLE X.—Annual and Semiannual Means of the Lunar-diurnal Variation of the Total Force at Hobarton, in parts of the Total Force at the Station.

Lunar Hours.		0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.
		·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
Semiannual Means ...	April to September..	+0002	−0005	−0007	−0011	−0006	−0001	+0003	+0005	+0004	+0006	−0003	−0002
	October to March...	+0005	+0005	−0002	−0001	0000	+0001	−0001	−0008	+0003	−0008	−0005	+0005
Annual Means		+0003	0000	−0004	−0006	−0003	0000	+0001	−0001	+0003	−0001	−0004	+0001

Lunar Hours.		12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.
		·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
Semiannual Means ...	April to September..	−0001	−0006	−0003	−0002	+0001	+0006	+0007	+0011	+0009	+0007	+0003	+0002
	October to March...	0000	−0003	−0001	+0002	−0005	−0002	0000	+0005	+0003	+0008	+0007	+0007
Annual Means		0000	−0004	−0002	0000	−0002	+0002	+0004	+0008	+0006	+0007	+0005	+0004

XX. *Contributions to Terrestrial Magnetism.—No.* X.

By Lieut.-General EDWARD SABINE, *R.A., President of the Royal Society.*

Received June 7,—Read June 14, 1866.

I RESUME in this Number of the Contributions the discussion and coordination of the observations of the Antarctic Magnetic Survey executed by Her Majesty's Ships 'Erebus' and 'Terror,' under the direction of Sir JAMES CLARK ROSS, R.N., aided by Captain FRANCIS RAWDON CROZIER, R.N., between the years 1839 and 1843.

I purpose in the present communication to complete the detailed exposition of the Survey by the reduction of the observations of the three magnetic elements in its concluding year, on the same general plan on which similar accounts were given of those of the preceding years in earlier communications, viz., between the Cape of Good Hope and Hobarton in 1840, and between the departure from Hobarton in November 1840, and the return to the same station in April 1841, in No. V. (Philosophical Transactions, 1843, Art. X.); and between Hobarton in July 1841 and the Falkland Islands in April 1842 in No. VI. (Philosophical Transactions, 1844, Art. VII.). The observations discussed in the present memoir are those made from the departure from the Falkland Islands in September 1842 to the second arrival at the Cape of Good Hope in April 1843. In a subsequent and concluding memoir, which I hope to present to the Society early in the ensuing session, it will be my endeavour to connect and thoroughly coordinate the several portions of the Survey, comprising in its three portions the circumnavigation of the Southern Ocean from the departure from the Cape of Good Hope in March 1840, to the return of the ships to the same station in April 1843.

The great work of M. GAUSS, the 'Allgemeine Theorie des Erdmagnetismus,' had been published in the 'Resultate des magnetischen Vereins' in 1839*. No more conclusive evidence could have been produced than was presented by that work, in support of the representations which had been made to Her Majesty's Government conjointly by the Royal Society and the British Association for the Advancement of Science, of the advisability of a southern magnetic Survey. The requisite *numerical values*, on which the practical application of the "Allgemeine Theorie" depended as a representation of the magnetic phenomena of the globe, and which were taken at equidistant meridional points on parallels of latitude, were necessarily limited, by the imperfection of our then knowledge, to *seven* such parallels, the most southern of which was the parallel of 40° south. The investigations and conclusions resulting from the Survey now under consideration, aided by the supplementary voyage of Her Majesty's Ship 'Pagoda,' under

---

* An English translation of this work was published in 1840 in the VI.th Part of TAYLOR's Scientific Memoirs.

Lieuts. MOORE, R.N, and CLERK, R.A. (Contribution No. VIII., Philosophical Transactions, 1846, Art. XVIII.), supply the means for a future revision of M. GAUSS's work, by the extension of the numerical values of the three elements to equidistant meridional points on three additional southern parallels, viz., those of 50°, 60°, and 70° of South Latitude.

In resuming the reduction and coordination of the observations of the Antarctic Magnetic Survey, it may be permitted to recall to remembrance that the system, in accordance with which the surveying compasses both of the 'Erebus' and 'Terror' were employed, was the same which had been originally adopted by the writer of these Contributions, and its practical value exemplified, in H.M. Ship 'Isabella,' in the first of the voyages of Arctic discovery in 1818, as described in the Philosophical Transactions for 1819, Art. VIII. The position of the standard compass, and the methods adopted to provide the data required for the investigation and eventual correction of the deviations occasioned by the disturbing influence of the ship's iron, were the same. In M. POISSON's 'Mémoire sur les déviations de la boussole produites par le fer des vaisseaux' (1838), the applications and verifications of the fundamental equations of his theory were exemplified and established by M. POISSON himself (pp. 47–49), by the accordance of their calculated results with the facts observed and recorded in the Arctic voyages of 1818, 1819, and 1820. The convenient and practical formulæ for computing the corrections of the three magnetic elements, which were subsequently derived from POISSON's fundamental Equations by Mr. ARCHIBALD SMITH (Philosophical Transactions, 1843, Art. X.), have since furnished, and still continue to furnish, the means of surmounting, even in an extreme case, such as that of a survey executed in the high magnetic latitudes of the southern hemisphere, and in dips even exceeding −88°, the serious embarrassments which would otherwise have been occasioned by the iron which necessarily formed part of the equipment of the ships. Sir JAMES ROSS was one of the junior midshipmen of the 'Isabella' in the voyage of 1818; and thus early commenced that interest in the general subject of Terrestrial Magnetism, and that practical acquaintance with the resources which modern science has introduced, by which in his subsequent career he has earned for himself and for his country so distinguished a place in the history of that great branch of physical geography.

The disturbance of the needle by the influence of the ship's iron, which the term "Deviation" is now generally employed to designate, was found both in the 'Erebus' and 'Terror' to be occasioned chiefly, if not wholly, by the magnetism induced in the iron of their fittings and equipment by the vertical part of the earth's force; and to be distributed symmetrically on either side of the fore-and-aft vertical section passing through the compass. It manifested itself consequently in the *southern* magnetic hemisphere, and in the usual place of the Standard Compass, by a repulsion of the north end of the compass needle from the ship's head, increasing with the increase of the earth's vertical magnetic force, and producing a deviation proportional to the tangent of the Inclination. The compass-card being divided into 360°, and counted from 0° at north successively to

90° at west, 180° at south, and 270° at east, the true magnetic direction was, everywhere in the southern hemisphere, *less* on the points from 0° to 180° and *more* on the points from 180° to 360°, than the amount actually shown by the compass-card. It thus happened that, as a general practice in the 'Erebus' and 'Terror' whilst in the southern hemisphere, the deviations were recorded as negative, or —, on the western side of the compass-card, and positive, or +, on its eastern side, the signs so employed having no direct relation whatever to the distinct question whether the Declination itself were easterly or westerly. In these Contributions, and in conformity with general usage in treatises on Terrestrial Magnetism, the *Declination* is counted *east* when the north end of the magnet *declines* from the Geographical North towards the *east*, and *west* when the declination *declines* towards the *west*; and as both east and west declinations are found in different parts of the southern magnetic hemisphere, east declinations being characteristic by the — sign, and west declinations by the + sign, the effect of the deviations having a — sign, was to augment the apparent or observed declination on the eastern points, and diminish it on the western points, in those parts of the hemisphere where the declination itself was east; and, *vice versâ*, to diminish the apparent or observed declination on the eastern points and augment it on the western points in those parts of the hemisphere where the declination itself was west.

Corrections applied to the Observations of the DECLINATION *for the Ship's Attraction.*

1. *In the 'Erebus.'*—In the subjoined Table (No. I.), columns 2 and 3 exhibit the deviations observed in the 'Erebus' on the points specified in column 1, at Port Louis in the Falkland Islands, on August 19, 1842, recorded in the Philosophical Transactions for 1844, page 88, and at Simon's Bay at the Cape of Good Hope on the 20th of April, 1843, which are now printed for the first time. As the observations at Port Louis were at the commencement of the third year's survey, and those at Simon's Bay at its close, and as the dip at the two stations was very nearly the same in amount, a mean of the deviations of the declination at the commencement and close of the year's survey has been adopted, and placed in column 4, as the foundation of the calculated deviations to be ascribed to intermediate times and localities. With these values of the deviation on the several points, the constants B, C, D, and E in the equations by which the deviations in dips of other amounts may be computed have been obtained, employing for that purpose the method described in the Philosophical Transactions for 1846, Art. XVIII., pages 350–352. The constants thus derived are as follows:—

$$B=-2^\circ\ 32'^{*};\quad C=-0^\circ\ 08';\quad D=+0^\circ\ 22';\quad E=+05'.$$

---

[*] B supplies the well-known coefficient a so much used in the earlier Numbers of these Contributions ($B=a\tan\theta$). Comparing only those values of a which were obtained after the arrival of the 'Erebus' in the Southern Hemisphere, the mean of the observations at Hobarton in 1840 and 1841 gave $a=\cdot0272$ (Philosophical Transactions, 1843, Art. X. p. 154); those at the Falkland Islands in August 1842, ·0292 (Philosophical Transactions, 1844, Art. VII. p. 88); and by the observations now discussed $a=\cdot0331$; the increased value being doubtless due to the magnetism acquired and temporarily retained in the high southern dips to which the 'Erebus' had been subject whilst in the Antarctic seas.

Column 5 contains the deviations computed with these constants, employing for that purpose the Table in pages 352, 353 of the same Number of the Contributions; and column 6 shows the differences between the deviations so computed for the dip of −53°, and the mean deviations observed at Port Louis, where the dip was −52° 20′, and at Simon's Bay, where it was −53° 26′. The differences are all well within the limits of errors of observation, and may justly be deemed insignificant. Employing the same coefficients, the deviations were computed corresponding successively to dips of −56°, −59°, −62°, and −65°, comprehending the whole range encountered in the third year's survey; and a Table was formed by interpolation for the intermediate degrees, which has been employed in correcting the Table of the declinations observed on board the 'Erebus' between Port Louis in August 1842, and the Cape of Good Hope in April 1843.

TABLE I.—'Erebus.' Deviations of the Declination at Port Louis and Simon's Bay.

1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
Ship's Head by compass.	Deviations observed.			Deviation computed.	Difference between the observed and computed.	Ship's Head by compass.	Deviations observed.			Deviation computed.	Difference between the observed and computed.
	Port Louis.	Simon's Bay.	Mean.				Port Louis.	Simon's Bay.	Mean.		
N.	+0° 12′	−0° 20′	−0° 04′	−0° 03′	0° 01′	S.	0° 06′	+0° 33′	+0° 16′	+ 0° 14′	0° 02′
N. by W.	−0 04	−0 37	−0 20	−0 25	0 05	S.E.	+0 44	+1 07	+0 55	+ 0 51	0 04
N.N.W.	−0 34	−1 04	−0 49	−0 46	0 03	S.S.E.	+1 13	+1 45	+1 29	+ 1 26	0 03
N.W. by N.	−0 50	−1 15	−1 02	−1 08	0 06	S.E. by S.	+1 41	+2 08	+1 54	+ 1 54	0 00
N.W.	−1 02	−1 42	−1 22	−1 31	0 09	S.E.	+1 55	+2 31	+2 13	+ 2 15	0 02
N.W. by W.	−1 01	−2 01	−1 31	−1 52	0 21	S.E. by E.	+2 07	+2 51	+2 29	+ 2 30	0 01
W.N.W.	−1 49	−2 35	−2 12	−2 12	0 00	E.S.E.	+2 19	+3 15	+2 47	+ 2 36	0 11
W. by N.	−2 10	−2 54	−2 32	−2 28	0 04	E. by S.	+2 16	+3 10	+2 43	+ 2 33	0 10
W.	−2 16	−3 10	−2 43	−2 37	0 06	E.	+2 07	+2 46	+2 26	+ 2 27	0 01
W. by S.	−2 21	−3 17	−2 49	−2 40	0 09	E. by N.	+1 54	+2 30	+2 12	+ 2 14	0 02
W.S.W.	−2 21	−3 09	−2 45	−2 38	0 07	E.N.E.	+1 44	+2 15	+2 00	+ 1 57	0 03
S.W. by W.	−2 04	−2 54	−2 29	−2 24	0 05	N.E. by E.	+1 17	+1 59	+1 38	+ 1 38	0 00
S.W.	−1 08	−2 27	−1 47	−2 03	0 16	N.E.	+0 51	+1 33	+1 12	+ 1 19	0 07
S.W. by S.	−1 03	−1 52	−1 27	−1 36	0 09	N.E. by N.	+0 41	+1 15	+0 58	+ 0 58	0 00
S.S.W.	−1 17	−1 12	−1 14	−1 02	0 12	N.N.E.	+0 41	+1 43	+0 42	+ 0 38	0 04
S. by W.	−0 39	−0 07	−0 23	−0 25	0 02	N. by E.	+0 28	+0 15	+0 21	+ 0 19	0 02

2. *In the 'Terror.'*—A precisely similar process has been pursued in computing the corrections to be applied for the influence of the ship's iron upon the observations of the declination in the 'Terror' in this portion of the survey, commencing at Port Louis in August 1842, and terminating at Simon's Bay, Cape of Good Hope, in April 1843.

The deviations on the thirty-two points observed at Port Louis in August 1843, have been already printed in a Table in No. VI. of these Contributions (Philosophical Transactions, 1844, Art. VII. p. 89); and those observed at Simon's Bay in April 1843 are now printed for the first time in page 457; their mean results are shown in the subjoined Table, No. II. The constants B, C, D, and E in the equations, by which the deviations in dips of other amounts may be derived, have been obtained in the manner already described in the case of the 'Erebus;' their values are

$$B=-2°\ 37'; \quad C=-0°\ 20'; \quad D=+0°\ 17'; \quad E=+0°\ 04'.$$

The deviations computed with these values for the dip of −53° are shown in column 5 of Table II., and column 6 of the same Table shows the differences between the observed and computed deviations in the dip of −53°. Employing the same constants, a Table of the deviations in dips of −56°, −59°, −62°, and −65°, with interpolated values at the intermediate degrees, has been computed, and has been employed in assigning the "corrections for deviation" in the Table of Declinations observed on board the 'Terror' between Port Louis in August 1842, and Simon's Bay in April 1843.

(Note.—It must be borne in mind that the "*corrections* for the ship's attraction," which appear in the Tables at the close of this and the earlier Numbers of these Contributions have, of course, the opposite signs to the "deviations" which they are designed to correct.)

Table II.—'Terror.' Deviations of the Declination at Port Louis and Simon's Bay.

1.	2.	3.	4.	5.	6.	1.	2.	3.	4.	5.	6.
Ship's Head by compass.	Deviations observed.			Deviation computed.	Difference between the observed and computed.	Ship's Head by compass.	Deviations observed.			Deviation computed.	Difference between the observed and computed.
	Port Louis.	Simon's Bay.	Mean.				Port Louis.	Simon's Bay.	Mean.		
N.	+0° 19′	−0° 58′	−0° 20′	−0° 16′	0° 04′	S.	−0° 16′	+0° 44′	+0° 14′	+0° 24′	0° 10′
N. by W.	−0 02	−1 03	−0 32	−0 40	0 08	S. by E.	−0 08	+1 56	+0 54	+1 01	0 09
N.N.W.	−0 17	−1 06	−0 42	−1 03	0 21	S.S.E.	0 00	+3 01	+1 30	+1 34	0 04
N.W. by N.	−0 48	−1 22	−1 05	−1 26	0 21	S.E. by S.	+0 47	+3 02	+1 54	+2 02	0 08
N.W.	−1 19	−2 20	−1 48	−1 48	0 00	S.E.	+1 35	+3 05	+2 20	+2 22	0 02
N.W. by W.	−1 49	−2 12	−2 00	−2 08	0 08	S.E. by E.	+2 17	+3 03	+2 40	+2 36	0 04
W.N.W.	−1 47	−3 14	−2 30	−2 23	0 07	E.S.E.	+3 04	+3 04	+3 04	+2 44	0 20
W. by N.	−2 07	−3 35	−2 51	−2 35	0 16	E. by S.	+2 33	+3 22	+2 57	+2 41	0 16
W.	−2 30	−3 36	−3 03	−2 41	0 22	E.	+2 46	+2 25	+2 35	+2 34	0 01
W. by S.	−2 21	−3 08	−2 44	−2 41	0 03	E. by N.	+2 27	+2 27	+2 27	+2 19	0 08
W.S.W.	−2 12	−2 35	−2 23	−2 33	0 10	E.N.E.	+1 58	+1 53	+1 55	+2 01	0 06
S.W. by W.	−2 21	−2 01	−2 11	−2 17	0 06	N.E. by E.	+1 39	+1 23	+1 31	+1 40	0 09
S.W.	−1 33	−1 33	−1 33	−1 53	0 20	N.E.	+1 13	+1 08	+1 10	+1 19	0 09
S.W. by S.	−1 05	−1 26	−1 15	−1 24	0 09	N.E. by N.	+1 11	+1 01	+1 06	+0 56	0 10
S.S.W.	−0 47	−1 22	−1 04	−0 52	0 12	N.N.E.	+0 34	+0 30	+0 32	+0 31	0 01
S. by W.	−0 45	−0 09	−0 27	−0 14	0 13	N. by E.	+0 27	−0 27	0 00	+0 08	0 08

Inclination *and* Total Force.

In the third year of the Antarctic Survey, as in the two preceding years, by far the greater part of the determinations both of the Inclination and of the Total Force were made at sea with Mr. Fox's apparatus, which is fully described (as well as the modes of employing it) in the article on Terrestrial Magnetism in the 'Admiralty Manual of Scientific Enquiry,' third edition, 1859, Appendix, No. 3. This apparatus was always used in the one selected spot in each ship; the face of the circle always towards the east (unless expressly mentioned otherwise), and the marked side of the needle towards the observer. The poles of the needle were at no time reversed, and great care was taken in mounting and dismounting it to avoid injury either to the axle or to the pivots.

The index-error occasioned by the face of the needle being always directed towards the east, was examined by comparison with results obtained with needles whose poles were reversed and the needle and circle used in the eight ordinary positions, whenever opportunities presented themselves for the comparison either on land or on ice. The needles were distinguished as R, F, 5 in the 'Erebus,' and F, C, B in the 'Terror.'

The dips were observed either "Direct" or by the aid of "Deflectors;" the intensities of the Force occasionally by weights and occasionally by deflectors; on land always by both methods, and at sea occasionally so. In the 'Erebus' and 'Terror,' in which the whole, or nearly the whole of the disturbance arising from the ship's iron was caused by induced magnetism, the deviation of the declination in the southern hemisphere was, as we have seen, a maximum to the East when the ship's head was to the West, and to the West when the head was to the East, passing through its zero when the ship's head was either north or south, or nearly so. In the *Inclination* and *Total Force*, on the other hand, the deviation (always speaking of the phenomena in the Southern Hemisphere) was a maximum when the ship's head was approximately either north or south, and passed through its zero as the ship's head was directed towards the east or towards the west. The dip of the south end of the magnet was least and the south polar force greatest when the ship's head was to the south, and the south dip greatest and the south polar force least when the head was to the north.

Corrections to be applied for the Deviations of the Inclination.

1. *In the 'Erebus.'*—The values of the constants c and d, employed in the correction of the deviations of the Inclination observed in this portion of the Survey, have been derived from the results obtained at the usual place of observation on board, with the ship's head on the different points of the compass, by the well-known process of "swinging the ship;" such results were obtained at Port Louis on the 17th of August, 1842, and at Simon's Bay on the 20th of April, 1843, the interval between those dates comprising the whole of the third year's survey. The observations made at Port Louis on the 17th of August, 1842, are printed in No. VI. of these Contributions (Philosophical Transactions, 1844, Art. VII., p. 168). Those at Simon's Bay on the 20th of April, 1843, will be found in page 459 of the present Number.

At Port Louis the mean of the results on the sixteen points was $-52° 24'$; and the Inclination observed on shore with the same instrument with the face of the circle also towards the east, and the needle observed "direct" and with "deflectors," was $-52° 28'$.

At Simon's Bay the mean on the sixteen points was $-53° 42'$, and the Inclination observed on shore with the same instrument, face east and needle "direct" and with "deflector S," was $-53° 37'\cdot5$. In both cases the mean of the results on the sixteen points has been taken as the standard of reference for assigning the deviation on the several points.

In the subjoined Table (Table III.), column 2 contains the dips observed at Port Louis on the different points of the compass specified in column 1; and column 3 the deviation on each point from the mean of the sixteen points stated at the foot of the column.

Columns 4 and 5 exhibit the same particulars at Simon's Bay. In column 6 is placed the mean deviation at the two stations, and in column 7 the mean deviation applied to −53° 0′ taken as an approximate mean dip common to both stations. In columns 8 and 9 are shown the values of ζ' and ζ on each point of the compass, ζ' being the azimuth of the ship's head by the standard compass, and ζ tabular or calculated values derived from the observed deviations of the declination on the same points. Column 10 contains the dips on the different points computed by the several constants, which are as follows:—

$$\left.\begin{array}{l} \mathrm{B}=a\tan\theta=-\cdot0441 \\ b=1-2\mathrm{D}=+\cdot9875 \end{array}\right\}\text{derived from the deviations of the Declination.}$$

$$\left.\begin{array}{l} c=+0\cdot0195 \\ d=+0\cdot9936 \end{array}\right\}\text{derived from the deviations of the Dip in column 7.}$$

And, finally, in column 11 are shown the differences between the observed and the computed deviations.

The values of c and d have been computed by equation (9) (Philosophical Transactions, 1843, p. 148) on all points excepting north and south; and on those points by equation (10). The computed dips by equation (13) on all points excepting east and west, on which points equation (12) has been substituted.

The Table for the correction of the deviations of the dip in the third year's survey has been formed by computing, by means of the above constants, the deviations in dips successively of −53°, −59°, and −65°, and interpolating the intermediate values.

TABLE III.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Ship's head by the Standard Compass.	Port Louis, August 1842.		Simon's Bay, April 1843.		Mean deviation.	Mean deviation applied to dip −53°.	Values of ζ'.	Values of ζ.	Computed dip. θ.	Observed dip + or − Computed.
	Dip on board.	Deviation from −52° 24′.	Dip on board.	Deviation from −53 42′.						
N.	−52° 53′	−29′	−54° 38′	−56′	−42′	−53° 42′	0° 0′	0° 00′	−53° 41′	−1′
N.N.W.	−52 50	−26	−54 31	−49	−38	−53 38	22 30	21 44	−53 40	+2
N.W.	−52 53	−29	−54 17	−35	−32	−53 32	45 00	43 29	−53 35	+3
W.N.W.	−52 39	−15	−54 02	−20	−18	−53 18	67 30	65 18	−53 20	+2
W.	−52 46	−22	−53 37	+5	−8	−53 08	90 00	87 23	−53 03	−5
W.S.W.	−52 17	+7	−53 16	+26	+16	−52 44	112 30	109 52	−52 55	+11
S.W.	−51 46	+38	−52 41	+61	+49	−52 11	135 00	132 57	−52 27	+16
S.SW.	−51 29	+55	−52 26	+76	+65	−51 55	157 30	156 25	−52 10	+15
S.	−51 36	+48	−52 24	+78	+63	−51 57	180 00	180 00	−52 06	+9
S.S.E.	−52 04	+20	−52 36	+66	+43	−52 17	202 30	203 56	−52 15	−2
S.E.	−52 18	+6	−53 13	+29	+18	−52 42	225 00	227 15	−52 32	−10
E.S.E.	−52 25	−1	−53 45	−3	−2	−53 02	247 30	250 06	−52 55	−7
E.	−52 27	−3	−54 21	−39	−21	−53 21	270 00	272 27	−53 03	−18
E.N.E.	−52 43	−19	−54 34	−52	−36	−53 36	292 30	294 27	−53 38	+2
N.E.	−52 43	−19	−54 21	−39	−29	−53 29	315 00	316 19	−53 41	+12
N.N.E.	−52 41	−17	−54 32	−50	−34	−53 34	337 30	338 08	−53 42	+8
	−52° 24′=Mean.		−53° 42′=Mean.			θ'	ζ'	ζ	θ	$\theta'-\theta$

2. *In the 'Terror.'*—The constants c and d in this ship have been derived from the

deviations observed on the sixteen principal points of the compass at Port Louis on August 15th, 1842, and at Simon's Bay on April 20th, 1843. The observations at Port Louis have been already printed in the Philosophical Transactions for 1844, Part II. p. 195. Those at Simon's Bay are now given in page 461 of the present communication. The results obtained with Needle F.C.B. by the *direct* observation have been employed for this purpose in preference to a mean between them and those obtained by deflector N., in consequence of a small uncertainty in the index-correction of the results with the deflector (Philosophical Transactions, 1844, Part II. Art. VII. p. 106). At Port Louis the arithmetical mean of the Inclinations observed on the sixteen points (−51° 31′) has been taken as the standard, by comparison with which the deviations on the several points have been assigned. The same needle, when observed on shore on the 25th of July, 1842, with the face of the circle towards the east, and the needle *direct*, gave

$$\begin{array}{rl} & \left.\begin{array}{r} -51^\circ\ 34'\cdot4 \\ -51\ \ 31\cdot6 \\ -51\ \ 31\cdot5 \\ -51\ \ 32\cdot2 \end{array}\right\}\text{Philosophical Transactions, 1844, Part II. p. 194.} \\ \text{Mean} & -51\ \ 32\cdot4 \end{array}$$

At Simon's Bay the arithmetical mean of the Inclinations observed with needle F.C.B. used "direct," and with the face of the circle towards the east, on the sixteen points, viz., −52° 40′, has been in like manner taken as the standard of comparison for the results on the several points. The same needle when observed with on shore on the 6th of April, face east and needle "direct," gave

$$\begin{array}{rl} & \left.\begin{array}{r} -52^\circ\ 49' \\ -52\ \ 45 \\ -52\ \ 47 \\ -52\ \ 47 \end{array}\right\}\text{page 531 of the present communication.} \\ \text{Mean} & -52\ \ 47 \end{array}$$

In the subjoined Table (Table IV.) column 2 contains the dips observed at Port Louis on the points of the compass specified in column 1, and column 3 the deviations on each point from the mean placed at the foot of column 2. Columns 4 and 5 exhibit the same particulars at Simon's Bay. In column 6 is placed the mean deviation at the two stations, and in column 7 the mean deviation applied to −53°, taken as an approximate mean dip at both stations. In columns 8 and 9 are shown the values of ζ' and ζ on each point, viz., ζ', the azimuth of the ship's head shown by the standard compass and consequently affected by the deviation, and ζ the true direction computed from the observed declinations and shown in Table II. Column 10 exhibits the dips on the several points computed by the coefficients;

$$\left.\begin{array}{l} B=a\tan\theta=-\cdot0458 \\ b=1-2D=+\cdot9901 \end{array}\right\}\text{derived from the deviations of the Declination.}$$

$$\left.\begin{array}{l} c=+0\cdot0106 \\ d=+0\cdot9950 \end{array}\right\}\text{derived from the deviations of the Dip in column 7.}$$

And, finally, in column 11 are shown the differences between the observed and the computed dips. The values of c and d have been derived by equation (9) (Philosophical Transactions, 1843, p. 148) on all the points from N.N.W. to S.S.W. and from N.N.E. to S.S.E.; and on the north and south points by equation (10): the computed dips by equation (13) on all points excepting east and west, and on those points by equation (12).

The Table for the correction of the deviations of the dip in the third year's survey has been formed by computing, by means of the coefficients above stated, the deviations in dips successively of −53°, −59°, and −65°, and interpolating the intermediate values.

Table IV.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Ship's head by the Standard Compass.	Port Louis, August 19th, 1842.		Simon's Bay, April 20th, 1843.		Mean deviation.	Mean deviation applied to dip −53°.	Values of ζ'.	Values of ζ.	Computed dip θ.	Observed dip + or −. Computed.
	Dip on board.	Deviation from −51° 31'.	Dip on board.	Deviation from −52° 40'.						
N.	−52° 25'	−54'	−53° 35'	−55'	−54'·5	−53° 54'·5	0° 0'	0° 0'	−53° 55'	+ 0'·5
N.N.W.	−52 14	−43	−53 29	−49	−46	−53 46	22 30	21 27	−53 50	+ 4·0
N.W.	−52 06	−35	−53 23	−43	−39	−53 39	45 0	43 12	−53 39	0·0
W.N.W.	−51 59	−28	−53 04	−24	−26	−53 26	67 30	65 07	−53 20	− 6·0
W.	−51 31	0	−52 52	−12	− 6	−53 06	90 0	87 19	−53 10	+ 4·0
W.S.W.	−51 11	+20	−52 22	+18	+19	−52 41	112 30	109 57	−52 38	− 3·0
S.W.	−50 48	+43	−51 48	+52	+47·5	−52 12·5	135 0	133 07	−52 09·5	− 3·0
S.S.W.	−50 43	+48	−51 24	+76	+62	−51 58	157 30	156 38	−51 54	− 4·0
S.	−50 12	+79	−51 22	+78	+78·5	−51 41·5	180 0	180 0	−51 50	+ 9·5
S.S.E.	−50 29	+62	−51 32	+68	+65	−51 55	202 30	204 05	−52 02	+ 7·0
S.E.	−50 45	+46	−52 02	+38	+42	−52 18	225 0	227 22	−52 23	+ 5·0
E.S.E.	−51 29	− 2	−52 34	+ 6	+ 2	−53 58	247 30	250 13	−52 50	− 8·0
E.	−51 46	−15	−53 01	−21	−18	−52 18	270 0	272 33	−53 10	− 8·0
E.N.E.	−52 16	−45	−53 19	−39	−42	−53 42	292 30	294 31	−53 45	+ 3·0
N.E.	−52 13	−42	−53 26	−46	−44	−53 44	315 0	316 20	−53 53	+ 9·0
N.N.E.	−52 14	−43	−53 24	−44	−43·5	−53 43·5	337 30	338 01	−53 56	+12·5
	−51° 31'=Mean.		−52° 40'=Mean.			θ'	ζ'	ζ	θ	$\theta'-\theta$

Variation in the Intensity of the Magnetic Force.

The Magnetic Survey which is here discussed was carried on chiefly by observations *made at sea*, and (in reference to the variations of the Magnetic Force especially) by instruments and methods either wholly novel or very nearly so. Some little repetition of what may have been already said some years ago must therefore be hazarded (and it is hoped will be pardoned), in the endeavour to convey an intelligible description of the methods by which the objects of the Survey were sought to be accomplished, and of the precautions which were adopted to supply, as far as circumstances would permit, the means of checking every part of the various processes.

The difficulty which presented itself on the first aspect, and whilst the survey was as yet only in the preliminary stage of contemplation, was to procure a proper *basis* for the determinations of the magnetic force. As the survey was designed to furnish not merely a map of the Isodynamic lines corresponding to the present epoch, but also such determinations as, repeated after the lapse of a century or centuries, should enable physicists of future times to derive and place on a satisfactory foundation a general theory of the *secular changes* to which the phenomena of each of the elements of terrestrial magnetism are known to be subject, it was necessary that the values of the magnetic force should be determined *in absolute measure*, at certain points which should serve as a base for the whole operations of the survey, and should be so situated as to embrace them all.

The difficulty which has been thus stated was surmounted by combining in one and the same recommendation to Her Majesty's Government, the prosecution of the Southern Magnetic Survey, and the establishment of fixed magnetic observatories at certain localities in the British Colonies, two of which, the Cape of Good Hope and Hobarton, were convenient of access and would comprehend between them nearly the whole of the isodynamic lines which should be included in the survey.

The groundwork of the survey, as regards the variations of the magnetic force, is thus to be found in the determinations made at the magnetic observatories of Hobarton and the Cape of Good Hope, of the absolute values of the magnetic force at those stations in and about the years in which the survey was in progress. A summary of the investigations on which these values are founded forms, therefore, a subject of primary consideration in this section of the present Contribution: pages 463 and 464.

The instruments and methods by which the variations of the magnetic force at other land stations than Hobarton and the Cape of Good Hope, and in the almost daily observations on board each of the ships, were investigated, were devised by Mr. ROBERT WERE FOX, F.R.S., and were described in publications at the date of their invention, and more recently in the 'Admiralty Manual of Scientific Enquiry,' Ed. 1859, Appendix No. 2. The mode of procedure for obtaining the ratios to an absolute value of the force determined at a base station has been explained in No. III. of these Contributions, Philosophical Transactions, 1842, Art. XI. page 9 *et seq.* In observations made at sea the ratios, whether obtained by constant weights or by deflectors, are liable to be affected by three sources of error, viz., (1) by the influence of the ship's iron, (2) by variations of temperature producing corresponding variations in the magnetism of the needle, and (3) by an alteration—progressive or sudden—which may possibly take place in the magnetism of the needle in the course of the survey, and which when it does occur is usually a loss of magnetism. Of these three sources of error the first is the most certain and important, and requires to be met by corrections investigated and applied in modes analogous to those already treated of in the cases of the Declination and of the Dip. The influence of variations of temperature on Mr. Fox's needles has always been found on investigation to be extremely small, and unless in cases when a more than ordinary accuracy is desired, the correction on this account may be regarded as insignificant. The third correction, or that for any notable change in the magnetism of the needle which may take place from time to time, may present greater difficulties than either of the two others, inasmuch as when such change has been shown to have occurred in the interval (sometimes of considerable length) between the comparisons made and repeated at base stations, it may not be always possible to assign the precise date at which the change commenced or terminated, or the proportions in which it should be allotted to different portions of the interval. It is always therefore extremely satisfactory to find, as will be shown to have been the case in the 'Erebus' and 'Terror,' that the intensity-needles preserved their magnetism absolutely without sensible change throughout the interval, *i. e.* in the present case from the time of their departure from Hobarton in April 1841 until their arrival at the Cape of Good Hope in April 1843: the investigation by which this is shown is subjoined; pp. 464 and 465. The correction of the sea observations for the influence of the ship's iron is subsequently discussed; viz., in p. 474.

Absolute Value in British Units of the Total Magnetic Force at the Hobarton Magnetic Observatory.

The experiments which were made at the Hobarton Magnetic Observatory for the determination of the absolute value of the total magnetic force in British units in the years when the Southern Survey was in progress, were (1) those of the absolute horizontal force, of which a fully detailed account was published in the first volume of the "Magnetical and Meteorological Observations at the Hobarton Observatory," printed in 1850, pp. 381–393; and (2) those of the Inclination, of which an also fully detailed account may be referred to in pp. 332–349 of the same volume.

For the horizontal force we find, in the preliminary discussion prefixed to the observational details in that volume, at p. xxxix., a summary of 399 results obtained by Captain Kay, R.N., and his assistants, with seven magnets of different lengths, between August 1843 and December 1848, of which the arithmetical mean is 4·4895 in British units, corresponding to about the middle of the year 1846. The mean secular change derived from a consecutive series of thirty-six months with the magnet which appeared to be entitled to the most dependence, was an annual decrease of ·0027: we have therefore 4·5000 as the absolute value of the horizontal force corresponding to the middle of the year 1842.

In the same preliminary discussion (p. lxxiii) the Inclination derived from eighty-seven monthly determinations between 1841 and 1848 is stated to be $-70° \, 35'{\cdot}6$, corresponding in epoch to May 1845; and as the annual secular change of the Inclination at Hobarton at the period in question had been found not to exceed a small fraction of a minute, the same value may be taken approximately as applicable to the middle of the year 1842.

Hence we obtain $4{\cdot}500 \times \sec. \, 70° \, 35'{\cdot}6 = 13{\cdot}540$ as (approximately) the total force in British units at the magnetic observatory at Hobarton in the middle of 1842.

Absolute Value in British Units of the Total Magnetic Force at the Cape of Good Hope Magnetic Observatory.

The experiments made at the Cape of Good Hope Observatory for the determination of the absolute value of the total force in British units at the time of the southern survey, were published in 1851 in vol. I. of the "Magnetical and Meteorological Observations at the Cape of Good Hope." Tables XXXV. and XXXVI. in pages lxiii to lxx of that volume, contain the details of thirty-five monthly determinations of the absolute horizontal force, extending, with occasional interruptions, from November 1846 to February 1850, giving as a mean result 4·4969 at the mean epoch of July 1848, and ·0061 as the rate of annual secular decrease between March 1846 and February 1850. Hence we obtain 4·5335 as an approximate value for the middle of the year 1842. Table XIX. p. 1 of the same volume exhibits the mean results of fifty-eight monthly determinations of the Inclination, extending from June 1841 to March 1846, of which the full details are given in pages 394 to 407. The arithmetical mean is $-53° 21'·1$, corresponding to Nov. 1, 1843, with a mean secular increase of south dip in each year of $5'·45$; whence the approximate inclination corresponding to the middle of 1842 is $-53° 13'·85$. We thus obtain $4·5335 \times \text{sec. } 53° 13'·85 = 7·5736$ as the approximate value of the total force in British units at the Cape Observatory, corresponding to the middle of 1842.

Simon's Bay, the anchorage of the 'Erebus' and 'Terror' in 1843, is about fifteen geographical miles south of the Cape Observatory, a difference which, in conformity with the maps of the isodynamic lines in that vicinity, may be regarded as equivalent to a difference of +0·024 of the Force, which, applied to the result at the observatory, gives 7·598 as approximately the total force at Simon's Bay in the middle of 1842.

Comparison of the results given by the needles employed in determining the ratios of the force in the sea observations, with the absolute values at Hobarton and the Cape of Good Hope.

The ratios of the force shown by these needles are measured by the angles of deflection produced in different localities by a constant weight applied to a grooved wheel attached to the axle of the needle; the intensity of the magnetic force being inversely as the sines of the angle of deflection. If we express by ϕ the absolute value of the force at a base station, and by v the deflection caused by a constant weight at the base station, and by ϕ' and v' corresponding values at another station, we have $\phi'=\phi \frac{\sin v}{\sin v'}$; and taking Hobarton as the base station, we have $\phi'=13·540 \frac{\sin v}{\sin v'}$. The weights employed were grains and half grains, several of each having been carefully prepared by Mr. Fox himself, and the same individual weights being, as far as possible, used throughout. The deflections caused by the different weights when the needles of the 'Erebus' and 'Terror' were observed at the magnetic observatory at Hobarton in April 1841, are shown in the following Table, the face of the circle being directed towards the east, which was its customary position in observations at sea.

TABLE V.

Erebus.			Terror.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	6 23·2	−1·04625	1·0	12 11·9	−1·32489
2	13 02·8	−1·05259	1·5	18 29·4	−1·32516
3	19 37·3	−1·04897	2·0	25 13·7	−1·32861
4	26 47·7	−1·05192	2·5	31 43·0	−1·32281
5	34 23·5	−1·05296	3·0	39 02·3	−1·32211
6	42 55·8	−1·05506	3·5	46 51·3	−1·31902
			4·0	56 10·9	−1·31744
	Mean...	−1·05139=NN ·11225		Mean...	−1·32286=NN ·21031

The weights and deflections observed on shore at Simon's Bay, Cape of Good Hope, in April 1843, with the face of the circle towards the east, were as follows:—

TABLE VI.

Erebus.			Terror.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1·0	11 19·5	−1·29308	0·5	11 21·7	−1·59550
2·0	23 43·0	−1·30343	1·0	22 21·1	−1·58011
3·0	36 59·4	−1·30224	1·5	34 09·1	−1·57317
3·5	44 21·0	−1·30043	2·0	48 18·9	−1·57218
4·0	55 52·2	−1·31585	2·5	66 40·8	−1·56505
	Mean...	−1·30301=NN ·20091		Mean...	−1·57720=NN ·37775

Hence we have the magnetic force at Simon's Bay, as derived from the needle of the 'Erebus' at Hobarton $13{\cdot}540\times\frac{\cdot11255}{\cdot20091}=7{\cdot}585$; and from the needle of the 'Terror' at Hobarton $13{\cdot}540\times\frac{\cdot21031}{\cdot37775}=7{\cdot}539$. The mean between these values is 7·562. The force at the anchorage of the 'Erebus' and 'Terror' corresponding to the mean epoch of 1842.5, derived from the absolute determinations at the magnetic observatory at the Cape of Good Hope (page 458), is 7·574.

The small difference in amount between the values derived from the absolute determinations at the Cape Observatory (including the correction to Simon's Bay), and that assigned from the Hobarton Observatory by the needles of the 'Erebus' and 'Terror,' is well within the limits of the errors of observation and of deduction; and gives full reason to infer that the magnetism of the needles underwent no material alteration in the interval.

Deduction of the Magnetic Force at the land stations visited intermediately between Hobarton in April 1841 *and Simon's Bay in April* 1843.

In this deduction we have the advantage that the deflections by the weights were observed with the face of the circle to the west as well as to the east at all the stations; (except in the case of the 'Terror' at St. Martin's Cove, when the deflections with the face of the circle to the west appear to have been accidentally omitted).

We have first to state the results at the base station at Hobarton with the face of the circle to the *West* in April 1842: those with the face of the circle to the East having been stated in page 465.

TABLE VII.

Erebus, circle face West.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	6 36·0	−1·06046	1·0	11 42·0	−1·30704
2	13 14·5	−1·05892	1·5	17 52·6	−1·31100
3	19 55·5	−1·05536	2·0	24 15·6	−1·31268
4	27 02·8	−1·05568	2·5	31 00·7	−1·31405
5	34 51·5	−1·05808	3·0	38 42·3	−1·31898
6	43 07·6	−1·05666	3·5	46 06·3	−1·31363
			4·0	56 10·5	−1·31740
	Mean...	−1·05753=NN ·11416		Mean...	−1·31354=NN ·20585

TABLE VIII.

Observations at Garden Island, Sydney; Lat. −33° 51′, Long. 151° 17′; July 1841.

Erebus, circle face East.			Erebus, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	6 58·6	−1·08445	1	7 01·4	−1·08732
2	13 57·5	−1·08137	2	14 32·7	−1·09889
3	21 13·8	−1·08172	3	21 51·4	−1·09376
4	29 09·2	−1·08560	4	29 32·1	−1·09075
5	37 43·3	−1·08766	5	37 38·9	−1·08693
6	46 51·8	−1·08501	6	47 32·5	−1·08977
	Mean...	−1·08430=NN ·12142		Mean...	−1·09124=NN ·12338

TABLE IX.

Terror, circle face East.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1·0	13 08·8	−1·35687	1·0	12 44·1	−1·34330
1·5	20 02·0	−1·35866	1·5	19 03·3	−1·33776
2·0	27 00 7	−1·35619	2·0	26 01·2	−1·34112
2·5	34 35·2	−1·35615	2·5	33 17·7	−1·34156
3·0	42 06·9	−1·34936	3·0	41 35·2	−1·34489
3·5	51 13·5	−1·34781	3·5	51 02·1	−1·34665
	Mean...	−1·35417=NN ·22603		Mean...	−1·34255=NN ·22006

Summary at Garden Island, Sydney.

Erebus.	Terror.
Face East $13{\cdot}540 \times \frac{\cdot 11255}{\cdot 12142} = 12{\cdot}551$ Face West $13{\cdot}540 \times \frac{\cdot 11416}{\cdot 12338} = 12{\cdot}529$ Mean...East and West=12·540	Face East $13{\cdot}540 \times \frac{\cdot 21031}{\cdot 22603} = 12{\cdot}598$ Face West $13{\cdot}540 \times \frac{\cdot 20585}{\cdot 22006} = 12{\cdot}665$ Mean...East and West=12.631
Mean ......Erebus and Terror=12·586	

Table X.

Observations at the Bay of Islands, New Zealand; Lat. −35° 16′, Long. 174° 00′; August and October 1841.

Erebus, circle face East.			Erebus, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	7 30·7	−1·11637	1	7 43·1	−1·12808
2	14 59·3	−1·11163	2	15 23·3	−1·12281
3	22 47·5	−1·11095	3	23 17·9	−1·12005
4	30 55·1	−1·10875	4	31 26·9	−1·11539
5	40 10·6	−1·11069	5	40 52·0	−1·11681
6	50 38·2	−1·11011	6	51 26·0	−1·11499
1	7 16·7	−1·10275	1	7 29·9	−1·11560
2	14 43·2	−1·10397	2	15 11·2	−1·11721
3	22 45·1	−1·11030	3	23 17·2	−1·11984
4	30 30·6	−1·10354	4	31 49·2	−1·11996
5	39 59·4	−1·10901	5	40 51·0	−1·11666
6	50 35·0	−1·10978	6	51 38·8	−1·11628
	Mean...	−1·10899=NN ·12853		Mean...	−1·11864=NN ·13136

Terror, circle face East.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1·0	14 03·2	−1·38529	1·0	13 24·3	−1·36518
1·5	21 17·9	−1·38409	1·5	20 30·5	−1·36840
2·0	28 22·1	−1·37579	2·0	27 46·9	−1·36746
2·5	36 50·7	−1·37990	2·5	35 43·0	−1 36831
3·0	44 58·3	−1·37215	3·0	44 38·7	−1·36966
3·5	55 09·9	−1·37017	35	55 23·7	−1·37137
1·0	13 51·7	−1·37945	1·0	13 26·8	−1·36650
1·5	20 53·0	−1·37593	1·5	20 16·4	−1·36362
2·0	28 22·4	−1·37586	2·0	27 38·8	−1·36550
2·5	37 05·6	−1·38246	2·5	35 45·1	−1·36868
3·0	45 02·2	−1·37264	3·0	44 47·7	−1·37080
3·5	55 19·1	−1·37098	3·5	55 26·4	−1·37162
	Mean...	−1·37706=NN ·23827		Mean...	−1·36805=NN ·23340

Summary at the Bay of Islands, New Zealand.

Erebus.	Terror.
Face East $13{\cdot}540 \times \frac{{\cdot}11255}{{\cdot}12853} = 11{\cdot}857$ Face West $13{\cdot}540 \times \frac{{\cdot}11416}{{\cdot}13136} = 11{\cdot}767$ Mean...East and West=11·812	Face East $13{\cdot}540 \times \frac{{\cdot}21031}{{\cdot}23827} = 11{\cdot}951$ Face West $13{\cdot}540 \times \frac{{\cdot}20585}{{\cdot}23340} = 11{\cdot}942$ Mean...East and West=11·946
Mean ......Erebus and Terror=11·879	

TABLE XI.—Observations at Port Louis, Falkland Islands; Lat. −51° 32′, Long. 301° 53′; April and August 1842.

Erebus, circle face East.			Erebus, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	8 56·8	−1·19177	1	9 20·5	−1·21037
2	18 31·2	−1·20090	2	18 50·5	−1·20811
3	27 42·7	−1·19036	3	28 30·0	−1·20154
4	37 58·1	−1·18698	4	38 51·0	−1·19540
5	48 45·9	−1·17726	5	51 28·0	−1·19737
6	66 49·9	−1·18533	6	68 40·3	−1·19103
1	8 41·2	−1·17907	1	9 17·1	−1·20776
2	17 57·2	−1·18786	2	18 32·9	−1·20154
3	27 43·3	−1·19050	3	28 26·7	−1·20077
4	37 40·4	−1·18409	4	39 05·3	−1·19764
5	49 31·4	−1·18223	5	51 19·3	−1·19350
6	67 23·5	−1·18712	6	69 35·8	−1·19371
	Mean...	−1·18696=NN ·15379		Mean...	−1·19990=NN ·15846

Erebus, circle face East.			Erebus, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	8 28·8	−1·16869	1	9 27·7	−1·21586
2	18 21·5	−1·19722	2	18 53·2	−1·20910
3	27 07·3	−1·18173	3	28 40·7	−1·20402
4	38 00·8	−1·18741	4	39 26·8	−1·20096
5	49 58·1	−1·19408	5	50 54·0	−1·19992
6	69 24·7	−1·19314	6	70 06·4	−1·19513
1	8 17·7	−1·15918	1	8 07·1	−1·14989
2	17 27·1	−1·17595	2	16 30·3	−1·15243
3	28 52·7	−1·19749	3	24 33·7	−1·14162
4	37 37·5	−1·18362	4	34 00·8	−1·14565
5	49 10·1	−1·17991	5	44 08·1	−1·14386
6	69 17·4	−1·19285	6	56 36·7	−1·14352
	Mean...	−1·18427=NN ·15285		Mean...	−1·17516=NN ·14968
Observations in Apr. and Aug.		·15379	Observations in Apr. and Aug.		·15846
,, ,, Nov. and Dec.		·15285	,, ,, Nov. and Dec.		·14957
Mean......		·15332	Mean......		·15401

Terror, circle face East.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.			grs.		
1·0	16° 56′·5	−1·46448	1·0	16° 14′·1	−1·44650
1·5	25 36·6	−1·45964	1·5	24 36·9	−1·44354
2·0	34 47·2	−1·45525	2·0	33 44·9	−1·44369
2·5	45 34·1	−1·45581	2·5	44 31·3	−1·44789
3·0	57 39·1	−1·44964	3·0	58 17·8	−1·45270
1·0	16 51·2	−1·46228	1·0	16 26·1	−1·45167
1·5	25 34·3	−1·45903	1·5	24 27·9	−1·44105
2·0	34 47·8	−1·45535	2·0	33 49·5	−1·44455
2·5	45 29·7	−1·45525	2·5	44 17·1	−1·44606
3·0	57 48·7	−1·45044	3·0	58 19·5	−1·45283
	Mean...	−1·45672=NN ·28623		Mean...	−1·44705=NN ·27993

Terror, circle face East.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.			grs.		
1·0	17° 00′·4	−1·46610	1·0	16° 15′·4	−1·44706
1·5	25 37·3	−1·45982	1·5	24 30·1	−1·44167
2·0	34 24·4	−1·45107	2·0	33 57·8	−1·44612
2·5	45 20·1	−1·45407	2·5	44 32·3	−1·44802
3·0	57 43·6	−1·45000	3·0	57 35·7	−1·44937
1·0	16 53·5	−1·46324			
1·5	25 39·2	−1·46032			
2·0	34 57·8	−1·45716			
2·5	45 42·4	−1·45684			
3·0	58 15·9	−1·45255			
1·0	17 07·1	−1·46886			
1·5	25 36·3	−1·45956			
2·0	34 53·5	−1·45639			
2·5	45 44·5	−1·45709			
3·0	57 57·8	−1·45112			
	Mean...	−1·45761=NN ·28682		Mean...	−1·44645=NN ·27955
Observations in April and July ...... ·28623 (weight 2) Aug., Nov., and Dec. ·28682 (weight 3) Mean, allowing weight ·28658			Observations in April and July ...... ·27993 (weight 2) August .... ·27955 (weight 1) Mean, allowing weight ·27980		

Summary at Port Louis, Falkland Islands.

Erebus.	Terror.
Face East $13·540 \times \frac{·11255}{·15332} = 9·940$ Face West $13·540 \times \frac{·11416}{·15401} = 10·037$ Mean, East and West= 9·988	Face East $13·540 \times \frac{·21031}{·28658} = 9·937$ Face West $13·540 \times \frac{·20585}{·27980} = 9·961$ Mean, East and West=9·949
Mean, Erebus and Terror =9·969.	

TABLE XII.—Observations at St. Martin's Cove, Cape Horn, Lat. −55° 51′, Long. 292° 28′, September and October 1842.

Erebus, circle face East.			Erebus, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′		grs.	° ′	
1	7 43·6	−1·12855	1	8 07·1	−1·14989
2	16 02·6	−1·14045	2	16 32·3	−1·15329
3	24 32·0	−1·14116	3	24 33·7	−1·14163
4	33 03·3	−1·13469	4	34 00·8	−1·14565
5	43 08·9	−1·13602	5	44 08·1	−1·14386
6	54 55·3	−1·13480	6	56 36·7	−1·14352
	Mean...	−1·13595=NN ·13676		Mean...	−1·14631=NN ·14006

Terror, circle face East.			Terror, circle face West.		
Weights.	Deflections.	Log sin corresponding to 1 grain.	Weights.	Deflections.	Log sin corresponding to 1 grain.
grs.	° ′				
1·0	15 04·0	−1·41488		(Not	observed.)
1·5	22 40·9	−1·41006			
2·0	30 34·6	−1·40543			
2·5	39 27·6	−1·40520			
3·0	48 56·6	−1·40029			
3·5	61 09·5	−1·39841			
	Mean...	−1·40571=NN ·25451			

Summary at St. Martin's Cove, Cape Horn.

Erebus.	Terror.
Face East $13·540 \times \frac{·11255}{·13676} = 11·143$ Face West $13·540 \times \frac{·11416}{·14006} = 11·036$ Mean East and West=11·090	Face East $13·540 \times \frac{·21031}{·25451} = 11·189$
Mean, Erebus (weight 2) and Terror (weight 1)=11·123.	

Land Stations at which the values of the magnetic elements have been determined with sufficient accuracy to justify their being regarded hereafter as Primary Stations.

Note.—It is intended to continue this Table in subsequent numbers of the Contributions.

Table XIII.

No.	Station.	Lat.	Long.	Declination.	Inclination.	Force.
1	Hobarton (Observatory).	−42° 52′	147° 24′	−10° 24′ Contrib. VI. p. 127.	−70° 36′ Contrib. X. p. 463.	13·540 Contrib. X. p. 463.
2	Sydney, Garden Island...	−33 51	151 17	− 9 51 Contrib. VI. p. 128.	−62 49 Contrib. VI. p. 100.	12·586 Contrib. X. p. 467.
3	Bay of Islands	−35 16	174 00	−13 36 Contrib. VI. p. 129.	−59 32 Contrib. VI. p. 100.	11·879 Contrib. X. p. 468.
4	Port Louis.................	−51 32	301 53	−17 36 Contrib. VI. p. 121.	−52 25 Contrib. VI. pp. 101–103*.	9·969 Contrib. X. p. 469.
5	St. Martin's Cove	−55 51	292 28	−22 56 Ross, Voy. vol. xi. p. 314.	−58 13 Contrib. X. p. 513.	11·123 Contrib. X. p. 470.
6	Cape of Good Hope	−33 56	18 29	−29 07 Cape Obs. vol. i. p. x.	−53 14 Contrib. X. p. 464.	7·574 Contrib. X. p. 464.

* The observations which were made at Port Louis between April 12th and August 23rd, 1842, to determine the Inclination with needles whose poles were reversed and the results obtained from the mean of the eight positions of the circle and needle, afford a favourable opportunity of judging of the accordance attainable in such results when the observations are made by skilled and careful observers, and when suitable instruments are employed. Sixty determinations were made with the Dip Circle of the 'Erebus' and its three needles R 4, R 6, and R 7, the observer being Lieut. A. J. Smith of the 'Erebus,' relieved occasionally by Mr. T. E. L. Moore of the 'Terror.' The results are detailed in the VI.th No. of these Contributions, pp. 101–103. The arithmetical mean of the sixty results is −52° 25′·06, and the probable error of a single result is ± 1′·52. It will be remembered that at the time these observations were made, the instruments which were used had already been employed for more than three years on a service of no ordinary exposure, and had been frequently disembarked for observations on land or on ice. The general accordance of the results, and the very small amount of the probable error of a single result, bear strong testimony to the care and skill of the observers, as well as to the improvement which took place in the English Dip Circles and Needles, in consequence of the pains taken by the participators in the Magnetic Survey of the British Islands in 1837 and 1838, of whom Sir James Ross was one. [Dr. Lloyd in the VII.th Volume of the Reports of the British Association, page 99, note 1; and Table III. in the same volume, p. 57.] The detailed statement of the observations at the Falkland Islands was published in the VI.th No. of these Contributions almost immediately after its receipt in England (in 1844), and afforded to all who were desirous of profiting by the instruction it conveyed a knowledge of the degree of accuracy which might be expected by the employment of the English Dip Circles and Needles, when placed in the hands of properly trained and careful observers. Even the small probable error of ±1′·52 was doubtless due in great measure to "magnetic disturbances" and to the effects of "horary variation, solar and lunar," the influence of which can only be eliminated by corrections supplied by the continuous record of the magnetometers of an observatory. The probable error of the *mean* of the sixty observations with the circle and needles of the 'Erebus' at Port Louis is ±0′·197.

Those who are interested in the accuracy with which observations of the Magnetic Dip may be made will recognize with interest and satisfaction that ±1′·52, the probable error of a single result derived from the 60 observations at Port Louis, is almost precisely the same as that (±1′·50) obtained by the mean of 282 independent results at the Kew Observatory (Proceedings of the Royal Society, March 1861) by several observers employing Dip Circles and Needles of the British pattern; in which results, as in those at Port Louis, no corrections for disturbing influences, derived from the continuous records of an observatory, were introduced.

Variation in the Intensity of the Magnetic Force observed by Deflectors.

1. *In the 'Erebus.'*—At sea, where manipulation of the weights causes exposure of the needle, which, in bad weather especially, is liable to occasion injury, the substitution of "deflecting magnets" for "weights" was frequently resorted to. In this case the ratios of intensity in different localities are inversely as the sines of the angles of deflection and directly as the weights equivalent to the deflecting force of the deflector on the needle at the respective angles; or $\phi'=\phi.\frac{\sin v}{\sin v'}.\frac{w'}{w}$, where ϕ, v, and w are the intensity, the angle of deflection, and the equivalent weight at a base station, and ϕ', v', and w' corresponding values in another locality. The method of forming a table of the equivalent weights corresponding to the deflecting force of a deflecting magnet at different angles has been explained in No. III. of these Contributions (Philosophical Transactions, 1842, Art. II. pp. 9 to 13); and a Table of the equivalent weights for the magnet R. F. 4 (used in the 'Erebus' either as Deflector S. or Deflector N., according as the Deflector was applied to either pole of the needle) is reprinted here (for convenience) from Contribution VI., Philosophical Transactions, 1844, Part 2, Art. VII. p. 114.

TABLE XIV.

Deflector S.								Deflector N.					
v'.	w'.	v'.	w'.	v'.	w'.	v'.	w'.	v'.	w'.	v'.	w'.	v'.	w'.
°	grs.	°	grs.	°	grs.	°	grs.	°	grs.	°	grs.	°	grs.
52	7·87	59	7·11	66	6·47	73	5·96	49	7·49	56	6·76	63	6·19
53	7·76	60	7·01	67	6·39	74	5·89	50	7·38	57	6·67	64	6·13
54	7·65	61	6·91	68	6·31	75	5·82	51	7·27	58	6·57	65	6·06
55	7·54	62	6·82	69	6·24	76	5·76	52	7·17	59	6·48	66	6·00
56	7·43	63	6·73	70	6·17	77	5·70	53	7·07	60	6·40	67	5·94
57	7·32	64	6·64	71	6·10	78	5·64	54	6·97	61	6·33	68	5·88
58	7·21	65	6·55	72	6·03	79	5·58	55	6·86	62	6·26	69	5·82

Regarding Hobarton as the base station of the whole of the Survey now under consideration, and 13·540 as the absolute value of the magnetic force in British units at Hobarton at the mean epoch of the Survey, the observations of the 'Erebus' at Hobarton in April 1841 supply the values $v=56° \ 28'\cdot7$ and (from Table XIV.) $w=7\cdot38$ grs., for Deflector S.; and $v=53° \ 02'\cdot7$ and $w=7\cdot07$ grs., for Deflector N; (for Hobarton). The angles of deflection in other localities furnish the respective values of v', and Table XIV. those of w' corresponding to the angles v'. Hence we have the values of the force in other localities; viz. $\phi'=\frac{\phi \sin v}{w}.w' \operatorname{cosec} v'=1\cdot53 \ w' \operatorname{cosec} v'$. The degree of accordance between the values of ϕ' obtained by weights in different localities and those obtained by the deflectors is shown in the following Table, in which are included all the stations on land or ice between Hobarton in April 1841 and Port Louis in December 1842.

TABLE XV.

Stations.	Lat.	Long.	R. F. 4. used as Deflector S.			R. F. 4 used as Deflector N.			Mean by Deflectors S. and N.	Mean by weights.
			v′.	w′.	φ′.	v′.	w′.	φ′.	φ′.	φ′.
Sydney	−33° 51′	151° 17′	59° 09′·0	grs. 7·09	12·63	55° 35′·9	grs. 6·77	12·55	12·59	12·59
Bay of Islands ...	−35 16	174 00	61 43·2	6·84	11·88	57 53·6	6·58	11·89	11·88	11·88
St. Martin's Cove..	−55 51	292 28	64 31·5	6·58	11·17	60 51·1	6·35	11·11	11·14	11·12
Falkland Islands...	−51 32	301 53	71 13·0	6·08	9·83	67 05·1	5·93	9·85	9·84	9·97

2. *In the 'Terror.'*—A spare needle, C, was employed in the 'Terror' as Deflector S. and Deflector N. according as the Deflector was applied to either pole of the Intensity needle; and two smaller magnets were used conjointly as "N. and S." The equivalent weights were obtained, as shown in the following Table, from the comparison of the angles of deflection with deflectors and weights at Hobarton in April 1841, Sydney in July 1841, Bay of Islands, New Zealand, in August and October 1841; Port Louis in the Falkland Islands from April to December 1842; St. Martin's Cove (Cape Horn) in October 1842; and Simon's Bay (Cape of Good Hope) in April 1843.

TABLE XVI.

Deflector S.				Deflector N.				Magnets N. and S.			
v′.	w′.	v′.	w′.	v′.	w′.	v′.	w′.	v′.	w′.	v′.	w′.
33°	grs. 2·625	42°	grs. 2·322	36°	grs. 2·794	45°	grs. 2·428	40°	grs. 3·175	49°	grs. 2·371
34	2·591	43	2·289	37	2·754	46	2·387	41	3·097	50	2·293
35	2·557	44	2·256	38	2·714	47	2·346	42	2·918	51	2·215
36	2·523	45	2·223	39	2·673	48	2·305	43	2·839	52	2·137
37	2·489	46	2·190	40	2·632	49	2·264	44	2·761	53	2·059
38	2·455	47	2·157	41	2·591	50	2·223	45	2·683		
39	2·421	48	2·122	42	2·550	51	2·182	46	2·605		
40	2·388	49	2·089	43	2·509	52	2·141	47	2·527		
41	2·355	50	2·055	44	2·468	53	2·100	48	2·449		

From the observations at Hobarton in April 1841 (regarded as a base station), we have $\varphi=13{\cdot}540$; v with Deflector S. 33° 23′, and w from Table XIV. 2·614; v with Deflector N. 36° 01′, and w 2·794; and v with Magnets N and S 40° 06′, and w 3·060. The angles of deflection in other localities furnish the several values of v', and Table XIV. the corresponding values of w'. Hence we obtain φ' in other localities, corresponding to 13·540 at Hobarton as the base station, by $\varphi'=\frac{\varphi \sin v}{w} . w' \operatorname{cosec} v'=2{\cdot}85\, w' \operatorname{cosec} v'$.

The degree of accordance between the values of φ' as obtained by weights or by deflectors is shown in the following Table.

TABLE XVII.

Stations.	Lat.	Long.	C, as Deflector S.			C, as Deflector N.			Mean by Deflectors.	Mean by Weights.
			v'.	w'.	ϕ'.	v'.	w'.	ϕ'.	ϕ'.	ϕ'.
Sydney	−33° 51′	151° 17′	35° 16′	grs. 2·549	12·58	38° 06′	grs. 2·710	12·52	12·55	12·59
Bay of Islands	−35 16	174 00	36 59	2·489	11·791	39 14	2·663	11·999	11·89	11·88
Port Louis............	−51 32	301 53	41 59	2·322	9·893	44 31	2·448	9·951	9·92	9·97
St. Martin's Cove...	−55 51	292 28	38 23	2·444	11·218	40 47	2·601	11·348	11·28	11·12
Simon's Bay	−34 11	18 26	50 14	2·048	7·594	52 36	2·117	7·595	7·59	7·60

Corrections for the influence of the ship's iron on the observations of the Intensity of the MAGNETIC FORCE.

The corrections to be applied to the intensity observations of the third year of the Survey have been derived from observations which were made with great care at Simon's Bay (Cape of Good Hope) in the 'Terror' on the 7th of April 1843, and in the 'Erebus' on the 12th of the same month, with the ship's head placed successively on each of the sixteen principal points as indicated by the standard compass. The arithmetical mean of the sixteen determinations has been regarded as a result in which the disturbing influences on the several points may be considered to have balanced each other, and as a true measure of the Force at the locality. The correctness of this conclusion was further established by the removal of the instruments from the ships to the shore, where the results obtained accorded well with the mean of the observations on the sixteen points on board.

In the formation of tables for the correction of the individual observations made at sea in the course of the year's survey, the values of the coefficients a, b, c, and d, determined by the investigations in the preceding parts of this communication, have been employed, viz.

In the 'Erebus' . . . $a=-{\cdot}0331$; $b=+{\cdot}9875$; $c=+0{\cdot}0195$; $d=+0{\cdot}9936$.
In the 'Terror' . . . $a=-{\cdot}0344$; $b=+{\cdot}9901$; $c=+0{\cdot}0106$; $d=+0{\cdot}9950$.

With these values tables of double entry were formed, having as arguments θ, and tabular values of ζ; employing for the Dip Corrections equations (12) and (13) (Philosophical Transactions, 1843, Art. X. p. 148); and for the Intensity Corrections $A'c\left(\frac{d}{c}\tan\theta+\cos\zeta\right)\cos\theta\,\mathrm{cosec}\,\theta'$ (Philosophical Transactions, 1843, Art. X. p. 162); A' in the 'Erebus' being found $=1{\cdot}0051$, and in the 'Terror' $=1{\cdot}0055$.

The application of these corrections to the observations with the ship's head on the different points at Simon's Bay, in April 1843, is shown in the following Table.

TABLE XVIII.—Values of the Intensity of the Force, as observed and as corrected, on the sixteen principal points of the compass at Simon's Bay in April 1843.

Erebus.			Terror.		
	Observed.	Corrected.		Observed.	Corrected.
N.	7·49	7·64	N.	7·44	7·59
N.N.W.	7·52	7·66	N.N.W.	7·45	7·59
N.W.	7·55	7·66	N.W.	7·45	7·56
W.N.W.	7·56	7·62	W.N.W.	7·37	7·43
W.	7·63	7·65	W.	7·58	7·60
W.S.W.	7·63	7·60	W.S.W.	7·68	7·65
S.W.	7·62	7·49	S.W.	7·72	7·59
S.S.W.	7·71	7·54	S.S.W.	7·73	7·56
S.	7·74	7·56	S.	7·79	7·61
S.S.E.	7·71	7·55	S.S.E.	7·80	7·64
S.E.	7·72	7·62	S.E.	7·72	7·62
E.S.E.	7·63	7·60	E.S.E.	7·61	7·58
E.	7·56	7·58	E.	7·56	7·58
E.N.E.	7·54	7·64	E.N.E.	7·48	7·58
N.E.	7·49	7·62	N.E.	7·41	7·54
N.N.E.	7·48	7·63	N.N.E.	7·38	7·53
	7·59	7·60		7·57	7·58

Index-corrections.—The cards of the Standard Compasses, both of the 'Erebus' and 'Terror,' were unchanged during the whole of the third year's survey. The index-corrections appear to have been very carefully watched and frequently examined. In memoranda preserved in the handwriting of Sir JAMES ROSS and of Captain CROZIER, the corrections are stated to have been constant from the departure of the ships from the Falkland Islands in September 1842 to their arrival at Simon's Bay in April 1843. The card of the 'Erebus' is stated by Sir JAMES ROSS to have had an index-correction of −1° 48′; those of the 'Terror,' as stated by Captain CROZIER,

$$\text{Card P} = -0^\circ\ 40', \text{ and Card R} = +1^\circ\ 13'.$$

The index-corrections of the inclination-needles employed in the 'Fox' circles in the sea observations (R. F. 5 in the 'Erebus,' and F. C. B. in the 'Terror') have been examined by comparing their results with those of needles whose poles were reversed and the inclination observed in the eight usual positions of the circle and needle, on several occasions at the same identical spots either on land or on the ice. With the needles of the 'Erebus' six such occasions presented themselves in the course of the three years' survey (confining the comparison to land stations sufficiently free from station error). They are as follows:—

TABLE XIX.

Stations.	Date.	Complete observations with reversed poles.	R. F. 5. Face East.	Index-correction. R. F. 5.	References.
Sydney …………………	July 1841 ……	−62° 49′·1	−62° 46′	− 3′·1	Cont. VI. pp. 100 & 153.
Bay of Islands …………	Aug. & Oct. 1841	−59 31·9	−59 28	− 3·9	Cont. VI. pp. 100 & 154.
On Ice {Lat. −63° 23′ Long. 210° 02′}	Dec. 1841 ……	−77 23·3	−77 15·5	− 7·8	Cont. VI. pp. 101 & 157.
On Ice {Lat. −65° 49′ Long. 202° 02′}	Jan. 1842 ……	−79 39·5	−79 35·8	− 3·7	Cont. VI. pp. 101 & 160.
St. Martin's Cove, Cape Horn ………………	Oct. 1842 ……	−58 12·8	−58 03·5	− 9·3	Cont. X. pp. 479 & 513.
On Ice {Lat. −64° 26′ Long. 303° 52′}	Jan. 1843 ……	−63 17·2	−63 10	− 7·2	Cont. X. pp. 513 & 505.
			Mean Index-correction of R. F. 5………	− 6·0	

A similar comparison for F. C. B. (the 'Fox' needle of the 'Terror') at five stations where the requisite data exist, is shown in the following Table.

TABLE XX.

Stations.	Date.	Complete observations with reversed poles.	F. C. B. Face East.	Index-correction. F. C. B.	References.
Hobarton ………………	April 1841 ……	−70° 39′·7	−70° 17′·3	−22′·4	Cont. V. pp. 165 & VI. 169.
Sydney …………………	July 1841 ……	−62 49·1	−62 22·4	−26·7	Cont. VI. pp. 100 & 170.
Bay of Islands …………	Aug. & Oct. 1841	−59 31·9	−58 50·6	−46·2	Cont. VI. pp. 100 & 172.
St. Martin's Cove ………	Oct. 1842 ……	−58 12·8	−57 28·0	−44·8	Cont. X. pp. 513 & 514.
On ice {Lat. −64° 26′ Long. 303° 52′}	Jan. 1843………	−63 17·2	−62 46·0	−31·2	Cont. X. pp. 513 & 519.
			Mean index-correction of F. C. B………	−34·3	Taken as −35′.

TABLE XXI.—General Table of the Declinations observed on board Her Majesty's Ships 'Erebus' and 'Terror,' between September 1842 and April 1843.

Lat.	Long.	Ship.	Declination.	Lat.	Long.	Ship.	Declination.
−51° 32′	301° 53′	Erebus.	−17° 36′*	−64° 14′	303° 56′	Terror.	−22° 11′
−54 16	305 05	Terror.	−17 29	−64 09	303 03	Erebus.	−21 32
−54 10	305 35	Terror.	−16 02	−64 12	303 04	Terror.	−23 33
−53 55	304 19	Erebus.	−18 18	−64 30	303 00	Erebus.	−23 00
−53 54	304 25	Terror.	−19 55	−64 28	303 20	Terror.	−24 23
−55 07	300 19	Terror.	−21 43	−64 37	303 16	Terror.	−22 50
−55 41	296 41	Terror.	−23 58	−64 44	303 12	Erebus.	−22 03
−56 00	292 44	Erebus.	−23 57	−64 42	303 20	Terror.	−24 08
−55 51	292 28	Erebus.	−22 56†	−64 44	303 10	Erebus.	−21 13§
−56 07	292 53	Terror.	−22 14	−64 41	302 52	Terror.	−23 52§
−55 39	295 23	Erebus.	−24 03	−64 42	303 10	Erebus.	−22 55
−55 42	295 20	Terror.	−24 50	−64 38	302 40	Terror.	−24 37
−55 35	299 09	Erebus.	−20 53	−64 38	302 40	Terror.	−24 07§
−55 29	299 03	Terror.	−24 06	−64 38	303 02	Erebus.	−23 57
−55 31	299 15	Erebus.	−21 51	−64 40	302 07	Terror.	−24 43
−54 32	299 53	Terror.	−22 04	−64 39	302 36	Erebus.	−22 14‖
−54 53	299 59	Erebus.	−21 10	−64 36	302 38	Erebus.	−23 11
−52 54	301 05	Terror.	−22 32	−64 42	302 42	Terror.	−25 59
−53 04	300 51	Erebus.	−19 48	−64 31	302 36	Erebus.	−23 37
−52 41	301 15	Terror.	−21 00	−64 32	302 55	Terror.	−23 34
−52 04	302 47	Erebus.	−18 03	−63 58	304 46	Erebus.	−20 22
−52 46	303 12	Terror.	−19 41	−64 04	305 05	Terror.	−22 42
−52 50	303 12	Erebus.	−18 29	−64 03	305 13	Terror.	−21 49
−53 50	303 49	Terror.	−20 22	−64 28	304 46	Erebus.	−21 25
−53 56	303 52	Erebus.	−17 35	−64 20	306 00	Terror.	−21 32
−55 45	305 17	Terror.	−20 12	−64 19	304 30	Erebus.	−22 03
−55 46	305 17	Erebus.	−18 47	−64 18	304 10	Erebus.	−21 28
−56 36	306 38	Erebus.	−17 47	−64 16	304 42	Terror.	−22 04
−56 48	306 41	Terror.	−21 09	−64 15	303 49	Erebus.	−21 03
−56 28	306 45	Erebus.	−17 59	−64 09	304 10	Terror.	−22 16
−58 29	308 13	Erebus.	−18 02	−64 12	303 53	Erebus.	−20 39
−58 25	308 00	Terror.	−20 06	−64 20	304 00	Terror.	−22 32
−59 28	308 20	Terror.	−21 29	−64 04	304 18	Erebus.	−20 50
−59 34	308 28	Erebus.	−17 56	−64 03	304 12	Terror.	−22 42
−62 00	307 52	Terror.	−22 06	−64 04	304 18	Erebus.	−20 48
−62 18	308 03	Erebus.	−18 24	−64 05	303 55	Terror.	−22 28
−62 20	308 12	Terror.	−22 43	−64 08	304 14	Erebus.	−20 55
−62 54	305 41	Erebus.	−20 16	−64 08	304 03	Erebus.	−21 41
−62 39	306 12	Terror.	−21 41	−64 05	303 55	Terror.	−22 28
−63 40	304 45	Terror.	−21 15	−64 04	303 58	Erebus.	−21 37
−63 48	304 52	Erebus.	−22 19	−64 00	304 22	Terror.	−23 02
−63 51	304 24	Terror.	−23 04	−64 08	303 47	Erebus.	−21 53
−64 14	304 21	Erebus.	−20 56	−64 09	303 57	Terror.	−22 13
−64 10	304 40	Terror.	−21 34	−63 56	305 22	Terror.	−21 10
−64 26	303 52	Erebus.	−22 51	−63 53	304 01	Erebus.	−20 36
−64 25	303 54	Terror.	−21 30	−64 25	305 30	Terror.	−22 17
−64 26	303 52	Erebus.	−20 50‡	−64 16	305 23	Erebus.	−20 37
−64 35	303 47	Erebus.	−23 51	−64 10	309 30	Terror.	−20 05
−64 38	304 20	Terror.	−22 50	−64 44	315 41	Erebus.	−13 58
−64 36	304 21	Erebus.	−21 50	−64 48	315 57	Terror.	−16 04
−64 38	304 26	Terror.	−22 44	−64 13	316 22	Erebus.	−13 43
−64 12	304 34	Erebus.	−20 01	−64 50	316 40	Terror.	−15 28

* Magnetometers on shore at Port Louis.

† Magnetometers on shore at St. Martin's Cove, Cape Horn.

‡ On ice.

§ On ice; Erebus, mean of 3 of Kater's compasses.

‖ On ice; mean of 3 compasses.

General Table of the Declinations (continued).

Lat.	Long.	Ship.	Declination.	Lat.	Long.	Ship.	Declination.
−64° 38′	316° 47′	Erebus.	−13° 46′	−64° 29′	346′ 02°	Erebus.	+ 4° 25′
−64 48	316 54	Erebus.	−13 49	−64 06	346 15	Terror.	+ 5 29
−65 04	318 24	Terror.	−14 25	−61 16	348 56	Erebus.	+ 8 51
−65 06	318 57	Erebus.	−13 20	−61 16	349 00	Terror.	+ 7 16
−65 13	319 20	Erebus.	−12 47	−57 46	351 52	Erebus.	+11 17
−63 58	321 40	Terror.	−10 11	−57 28	351 40	Terror.	+10 35
−63 56	321 43	Erebus.	− 8 59	−57 22	352 12	Erebus.	+13 10
−63 56	322 14	Erebus.	− 9 24	−57 16	352 54	Terror.	+11 33
−62 38	328 00	Terror.	− 7 37	−57 10	352 53	Erebus.	+12 28
−62 50	328 20	Erebus.	− 7 54	−57 04	352 52	Erebus.	+14 57
−62 37	328 30	Erebus.	− 2 50	−56 42	353 40	Terror.	+11 22
−62 16	330 30	Terror.	− 6 30	−56 34	353 46	Erebus.	+13 46
−62 20	330 30	Erebus.	− 4 41	−55 58	355 32	Erebus.	+13 21
−62 06	333 43	Erebus.	− 3 53	−55 58	355 30	Terror.	+12 57
−62 02	333 40	Terror.	− 2 50	−55 53	355 44	Erebus.	+13 14
−61 55	333 48	Erebus.	− 3 38	−54 30	357 50	Terror.	+13 52
−62 00	333 44	Terror.	− 2 35	−54 28	357 45	Erebus.	+16 48
−61 36	336 20	Erebus.	− 0 44	−54 06	359 38	Erebus.	+17 11
−61 33	335 30	Terror.	− 0 44	−54 15	0 0	Terror.	+14 49
−62 24	343 58	Erebus.	+ 5 19	−50 00	9 35	Erebus.	+24 12
−62 20	344 00	Terror.	+ 3 29	−49 57	9 38	Terror.	+24 07
−62 52	344 33	Erebus.	+ 4 40	−48 20	10 44	Erebus.	+25 35
−64 04	345 07	Terror.	+ 4 17	−47 20	10 55	Terror.	+24 30
−64 04	345 16	Erebus.	+ 5 18	−47 20	11 04	Erebus.	+25 22
−64 24	347 27	Terror.	+ 4 39	−43 28	13 25	Terror.	+26 46
−65 08	349 50	Erebus.	+ 7 02	−43 49	13 38	Erebus.	+29 26
−65 01	349 04	Terror.	+ 5 58	−43 17	14 34	Erebus.	+28 13
−66 00	351 00	Terror.	+ 8 22	−43 08	14 40	Terror.	+27 33
−66 01	353 00	Erebus.	+ 9 06	−43 03	14 50	Erebus.	+28 32
−67 12	350 36	Terror.	+ 7 08	−41 51	15 03	Terror.	+27 29
−66 40	350 39	Erebus.	+ 9 01	−41 56	15 07	Erebus.	+27 42
−68 00	348 21	Erebus.	+ 6 34	−41 30	15 14	Erebus.	+30 01
−68 08	348 10	Terror.	+ 4 15	−40 22	16 00	Terror.	+26 53
−68 18	347 20	Erebus.	+ 5 37	−39 23	16 08	Terror.	+27 53
−68 32	347 09	Erebus.	+ 4 43	−39 43	15 45	Erebus.	+28 29
−68 30	346 50	Terror.	+ 4 15	−38 26	16 39	Terror.	+27 43
−69 36	345 18	Erebus.	+ 3 05	−37 50	16 35	Erebus.	+29 28
−69 42	345 20	Terror.	+ 1 53	−36 15	16 31	Terror.	+28 43
−70 50	343 21	Erebus.	+ 2 18	−33 36	16 36	Erebus.	+28 26
−70 51	343 33	Terror.	+ 2 23	−35 50	16 35	Erebus.	+30 15
−70 44	343 48	Terror.	+ 2 21	−36 36	16 22	Erebus.	+28 49
−70 24	341 56	Terror.	− 2 00	−35 26	16 14	Terror.	+28 00
−71 14	344 18	Erebus.	+ 3 23	−35 17	16 29	Erebus.	+30 44
−66 10	346 40	Terror.	+ 5 35	−35 03	17 13	Erebus.	+30 32

Table XXII.—General Table of the Inclinations observed on board Her Majesty's Ships 'Erebus' and 'Terror,' between September 1842 and April 1843.

Lat.	Long.	Ship.	Inclination.	Lat.	Long.	Ship.	Inclination.
−51° 32′	301° 53′	Erebus.	−52° 34′	−56° 34′	306° 39′	Erebus.	−56° 14′
−51 32	301 53	Terror.	−51 51	−56 55	306 40	Terror.	−56 09
−52 48	303 10	Terror.	−53 52	−57 50	307 58	Terror.	−57 17
−53 33	302 05	Erebus.	−53 34	−58 16	308 00	Erebus.	−57 21
−54 02	305 30	Terror.	−53 39	−58 25	307 53	Terror.	−57 14
−54 03	305 26	Erebus.	−54 31	−59 28	308 20	Erebus.	−58 46
−53 42	305 04	Terror.	−53 39	−59 57	307 53	Terror.	−58 33
−53 47	304 48	Erebus.	−54 25	−61 23	307 41	Erebus.	−59 51
−54 40	304 35	Terror.	−53 24	−61 20	307 42	Terror.	−59 47
−54 43	304 30	Erebus.	−54 44	−62 12	307 47	Terror.	−60 45
−54 42	305 30	Terror.	−54 39	−62 14	307 55	Erebus.	−61 03
−54 41	304 48	Erebus.	−54 16	−62 25	307 58	Terror.	−60 21
−55 10	301 00	Terror.	−56 06	−62 31	308 05	Erebus.	−60 34
−55 08	300 44	Erebus.	−56 33	−62 18	308 17	Terror.	−61 17
−55 30	297 00	Terror.	−57 33	−62 22	308 00	Erebus.	−60 36
−55 40	296 52	Erebus.	−57 33	−62 18	308 24	Erebus.	−61 04
−56 25	293 07	Erebus.	−58 52	−62 30	306 52	Terror.	−62 04
−56 25	293 07	Erebus	−58 37	−62 30	306 30	Erebus.	−61 18
−55 51	292 28	Erebus.	−58 12*	−62 42	305 27	Terror.	−61 47
−55 51	292 28	Terror.	−58 12*	−63 13	305 33	Terror.	−62 17
−55 51	292 28	Erebus.	−58 03†	−63 35	305 47	Terror.	−62 31
−56 02	292 57	Terror.	−59 08	−63 36	305 00	Erebus.	−62 18
−55 52	295 41	Terror.	−57 18	−63 39	304 40	Erebus.	−62 29
−55 38	296 00	Erebus.	−56 46	−63 57	304 32	Terror.	−62 41
−55 38	295 54	Terror.	−57 08	−63 45	304 40	Erebus.	−61 56
−55 58	299 12	Erebus.	−56 53	−64 15	304 25	Terror.	−63 28
−55 56	299 17	Terror.	−56 36	−64 23	304 00	Erebus.	−63 04
−55 32	299 08	Erebus.	−56 21	−64 26	303 52	Erebus.	−63 16‖
−55 28	298 35	Terror.	−57 00	−64 27	303 54	Terror.	−63 21‖
−55 05	299 49	Terror.	−56 34	−64 26	303 54	Terror.	−63 11
−54 24	300 08	Erebus.	−55 06	−64 29	304 18	Erebus.	−62 48
−54 40	301 32	Terror.	−56 15	−64 06	303 43	Terror.	−63 22
−54 36	301 37	Terror.	−56 09	−64 12	304 04	Erebus.	−63 01
−52 26	301 16	Terror.	−53 39	−64 36	304 26	Terror.	−62 54
−52 52	301 05	Erebus.	−53 32	−64 13	304 06	Terror.	−63 13
−52 36	301 16	Terror.	−53 26	−64 13	304 06	Terror.	−63 00
−51 32	301 53	Terror.	−52 13‡	−64 12	303 04	Terror.	−63 24
−51 32	301 53	Erebus.	−52 49‡	−64 34	302 50	Erebus.	−63 36
−51 32	301 53	Terror.	−52 18‡	−64 36	302 52	Terror.	−63 36
−51 32	301 53	Terror.	−52 00§	−64 36	302 52	Terror.	−63 51
−51 32	301 53	Erebus.	−52 42	−64 35	302 13	Erebus.	−63 30
−51 32	301 53	Terror.	−51 56	−64 37	303 10	Terror.	−63 38
−52 50	303 07	Erebus.	−53 29	−64 37	303 10	Terror.	−63 48
−52 46	303 18	Terror.	−52 49	−64 44	303 07	Erebus.	−63 21¶
−52 52	303 20	Terror.	−52 43	−64 44	303 07	Terror.	−63 44¶
−53 38	303 43	Terror.	−53 11	−64 40	302 40	Erbrus.	−63 30
−54 23	303 59	Erebus.	−54 43	−64 40	303 08	Terror.	−63 52
−55 26	305 20	Terror.	−54 32	−64 35	303 06	Terror.	−63 55
−55 57	305 27	Terror.	−55 03	−64 36	302 07	Terror.	−64 06
−55 51	305 18	Erebus.	−55 35	−64 36	302 07	Terror.	−63 58
−56 00	305 30	Terror.	−55 15	−64 42	302 42	Terror.	−63 55

* On shore, St. Martin's Cove, Cape Horn, with needles whose poles were reversed.

† On shore, St. Martin's Cove, Cape Horn, with needle R. F. 5.

‡ On shore, Falkland Island, Port Louis. § On board with needle F.C.B.

‖ On ice, true dip observed by needles whose poles were reversed −63 17·2. ¶ On ice.

General Table of Inclinations (continued).

Lat.	Long.	Ship.	Inclination.	Lat.	Long.	Ship.	Inclination.
−64° 31′	302° 34′	Erebus.	−63° 38′	−64° 43′	312° 06′	Terror.	−61° 56′
−64 34	302 43	Terror.	−63 49	−64 36	311 53	Erebus.	−61 41
−64 28	303 03	Erebus.	−63 06	−64 37	314 21	Erebus.	−62 07
−64 26	303 05	Terror.	−63 04	−64 38	314 01	Terror.	−61 44
−64 28	303 03	Erebus.	−63 43*	−64 39	316 04	Erebus.	−61 30
−64 28	303 03	Terror.	−63 40*	−64 49	315 07	Terror.	−61 34
−64 22	303 30	Terror.	−63 29	−64 38	316 57	Erebus.	−61 57
−63 58	304 46	Erebus.	−62 54	−64 47	316 57	Terror.	−62 19
−64 56	305 25	Terror.	−62 28	−65 06	318 46	Erebus.	−61 35
−64 00	305 24	Terror.	−62 50	−64 58	318 26	Terror.	−61 48
−64 22	305 01	Erebus.	−63 08	−64 40	320 12	Erebus.	−61 08
−64 22	305 44	Terror.	−63 29	−64 37	320 28	Terror.	−61 00
−64 18	304 18	Erebus.	−63 20	−63 54	321 36	Erebus.	−60 27
−64 16	304 26	Terror.	−63 26	−64 02	321 55	Terror.	−60 33
−64 19	304 04	Erebus.	−63 00	−63 59	324 18	Terror.	−60 01
−64 18	304 13	Terror.	−63 14	−63 36	324 36	Erebus.	−59 42
−64 12	303 50	Erebus.	−62 26	−62 37	328 17	Terror.	−58 52
−64 12	304 07	Terror.	−63 04	−62 13	330 38	Terror.	−58 30
−64 24	304 49	Erebus.	−62 47	−62 39	328 16	Erebus.	−58 42
−64 20	304 08	Terror.	−63 20	−62 20	330 00	Erebus.	−58 36
−64 24	304 49	Erebus.	−62 26	−62 05	333 38	Terror.	−57 57
−64 16	304 44	Terror.	−62 55	−61 59	333 43	Erebus.	−58 13
−64 15	304 00	Erebus.	−62 56	−61 37	336 05	Erebus.	−58 18
−64 16	304 17	Terror.	−63 20	−61 32	336 10	Terror.	−58 01
−64 04	305 19	Erebus.	−62 57	−61 30	338 00	Erebus.	−57 50
−64 01	304 20	Terror.	−63 03	−61 28	337 42	Terror.	−58 00
−64 08	304 09	Erebus.	−62 42	−61 13	340 00	Terror.	−57 57
−64 08	304 08	Erebus.	−62 38	−61 46	341 02	Erebus.	−58 18
−64 14	304 04	Terror.	−63 09	−62 36	344 08	Erebus.	−59 12
−64 09	304 06	Terror.	−63 13	−62 41	343 18	Terror.	−59 01
−64 05	304 00	Erebus.	−62 46	−63 58	345 10	Erebus.	−60 42
−64 08	304 02	Terror.	−63 14	−64 14	345 30	Terror.	−60 45
−64 09	303 57	Erebus.	−63 00	−64 38	348 00	Erebus.	−61 21
−64 07	303 58	Terror.	−63 07	−64 27	347 32	Terror.	−61 28
−64 00	304 42	Erebus.	−62 23	−65 12	350 05	Erebus.	−61 49
−64 01	304 42	Terror.	−62 44	−65 00	349 30	Terror.	−61 39
−63 53	304 51	Erebus.	−62 28	−65 12	350 00	Terror.	−61 53
−64 00	304 47	Terror.	−63 01	−66 00	353 00	Terror.	−63 02
−64 16	304 38	Erebus.	−62 33	−66 08	352 43	Erebus.	−63 14
−64 19	304 43	Terror.	−63 12	−66 02	353 13	Terror.	−63 08
−64 17	305 20	Erebus.	−62 22	−66 54	351 15	Terror.	−63 32
−64 17	304 41	Terror.	−63 01	−67 06	351 04	Erebus.	−63 19
−64 18	305 40	Terror.	−63 08	−67 05	351 00	Terror.	−63 37
−64 16	304 47	Erebus.	−62 44	−68 14	347 08	Erebus.	−64 24
−64 12	305 17	Terror.	−62 49	−68 08	348 10	Terror.	−64 14
−64 11	305 13	Terror.	−62 58	−68 32	347 09	Erebus.	−64 21
−63 34	307 00	Erebus.	−61 35	−68 32	347 12	Terror.	−64 14
−63 34	307 00	Terror.	−61 53	−69 26	345 31	Erebus.	−64 48
−63 35	307 33	Erebus.	−61 37	−69 24	345 30	Terror.	−65 24
−63 36	307 35	Terror.	−62 22	−71 10	344 13	Erebus.	−66 13
−63 54	308 00	Erebus.	−61 50	−71 09	344 10	Terror.	−66 44
−63 56	308 00	Terror.	−62 12	−71 08	344 18	Terror.	−66 44
−64 05	308 03	Terror.	−61 31	−70 55	343 14	Erebus.	−65 31
−63 49	308 52	Terror.	−62 03	−70 33	343 23	Terror.	−64 51
−63 49	309 00	Erebus.	−62 08	−70 28	342 39	Erebus.	−65 38
−64 18	309 40	Terror.	−62 06	−70 28	342 26	Terror.	−66 00
−64 19	309 36	Erebus.	−62 33	−69 56	344 03	Erebus.	−64 04

* On ice.

General Table of Inclinations (continued).

Lat.	Long.	Ship.	Inclination.	Lat.	Long.	Ship.	Inclination.
−69° 36′	344° 15′	Terror.	−64° 35′	−50° 19′	9° 15′	Terror.	−55° 54′
−68 06	344 40	Erebus.	−63 01	−47 38	10 51	Erebus.	−55 39
−68 07	346 13	Terror.	−63 14	−47 36	10 41	Terror.	−55 46
−65 56	346 24	Erebus.	−61 47	−45 38	11 52	Terror.	−55 21
−65 57	346 40	Terror.	−62 07	−45 32	11 54	Erebus.	−55 18
−64 31	346 01	Erebus.	−59 50	−43 55	13 16	Terror.	−55 02
−63 58	346 25	Terror.	−60 24	−43 57	13 16	Erebus.	−54 28
−61 34	348 37	Erebus.	−58 50	−43 15	14 30	Terror.	−55 13
−61 35	349 00	Terror.	−58 52	−43 10	14 44	Erebus.	−54 40
−59 34	350 34	Erebus.	−57 27	−43 11	14 43	Terror.	−55 10
−59 21	350 36	Terror.	−57 29	−41 58	15 11	Terror.	−54 52
−57 35	352 00	Terror.	−56 26	−41 40	15 09	Erebus.	−54 43
−57 27	352 08	Terror.	−56 24	−40 15	15 47	Erebus.	−54 50
−57 27	352 08	Erebus.	−56 37	−40 07	16 08	Terror.	−54 33
−57 09	352 44	Terror.	−56 15	−37 40	16 40	Erebus.	−54 32
−57 09	352 45	Erebus.	−56 28	−38 00	16 45	Terror.	−54 04
−56 38	353 57	Erebus.	−56 06	−36 02	16 32	Terror.	−53 27
−56 44	353 45	Terror.	−56 04	−35 59	16 34	Erebus.	−54 06
−55 38	355 32	Erebus.	−56 45	−35 26	16 22	Erebus.	−53 45
−55 56	355 39	Terror.	−55 08	−35 21	16 22	Terror.	−53 05
−54 31	357 35	Erebus.	−55 36	−35 04	17 08	Erebus.	−53 24
−54 32	357 26	Terror.	−54 50	−35 03	17 06	Terror.	−53 10
−54 07	359 56	Erebus.	−55 37	−35 04	17 08	Erebus.	−53 24
−54 06	359 50	Terror.	−55 20	−34 11	18 26	Terror.	−53 35*
−50 52	8 47	Terror.	−56 04	−34 11	18 26	Erebus.	−53 40*
−50 37	9 03	Erebus.	−56 09				

* On shore at Simon's Bay.

Table XXIII.—General Table of the Intensity of the Magnetic Force from the Observations on board Her Majesty's Ships 'Erebus' and 'Terror,' between September 1842 and April 1843.

Lat.	Long.	Ship.	Intensity. British units.	Lat.	Long.	Ship.	Intensity. British units.
−51° 32′	301° 53′	Erebus.	9·82	−62° 42′	305° 27′	Terror.	11·51
−53 03	302 05	Erebus.	9·92	−62 36	306 20	Erebus.	11·39
−52 48	303 10	Terror.	10·29	−63 35	305 47	Terror.	11·70
−54 03	305 26	Erebus.	9·92	−63 36	305 00	Erebus.	11·40
−53 47	304 48	Erebus.	9·93	−63 57	304 32	Terror.	11·69
−54 43	304 30	Erebus.	10·02	−63 39	304 40	Erebus.	11·56
−54 42	304 46	Erebus.	10·06	−64 23	304 00	Erebus.	11·79
−54 42	305 30	Terror.	10·35	−64 27	303 54	Terror.	11·79‡
−55 30	297 00	Terror.	11·04	−64 26	303 52	Erebus.	11·69‡
−55 40	296 52	Erebus.	10·73	−64 30	304 10	Terror.	11·76
−55 47	293 00	Erebus.	10·71	−64 32	304 20	Erebus.	11·69
−55 51	292 28	Erebus.	11·13*	−64 38	304 20	Terror.	11·70
−55 51	292 28	Terror.	11·19*	−64 18	308 39	Erebus.	11·55
−56 02	292 57	Erebus.	11·34	−64 13	304 06	Terror.	11·79
−56 02	292 57	Terror.	11·40	−64 13	304 06	Terror.	11·77
−55 52	295 41	Terror.	10·90	−64 12	303 04	Terror.	11·88
−55 39	296 00	Erebus.	10·87	−64 34	302 50	Erebus.	11·75
−54 24	300 08	Erebus.	10·36	−64 28	303 20	Terror.	11·87
−55 05	299 49	Terror.	10·91	−64 44	303 07	Erebus.	11·74
−52 52	301 05	Erebus.	10·11	−64 44	303 07	Erebus.	11·76‡
−52 26	301 16	Terror.	10·00	−64 41	302 52	Terror.	11·82
−51 32	301 53	Erebus.	9·90†	−64 48	303 09	Erebus.	11·71‡
−51 32	301 53	Terror.	9·92†	−64 48	303 09	Terror.	11·85‡
−51 32	301 53	Erebus.	9·99†	−64 38	302 40	Terror.	11·81
−51 32	301 53	Terror.	9·91†	−64 31	302 34	Erebus.	11·69
−51 36	301 45	Terror.	9·89	−64 30	303 04	Terror.	11·92
−52 50	303 07	Erebus.	10·01	−64 40	302 07	Terror.	11·79
−52 46	303 18	Terror.	10·03	−64 48	303 09	Erebus.	12·03
−54 23	303 59	Erebus.	10·25	−64 48	303 09	Erebus.	11·71‡
−53 38	303 43	Terror.	10·12	−64 04	305 00	Terror.	11·66
−55 51	305 18	Erebus.	10·25	−64 22	305 01	Erebus.	11·56
−55 26	305 20	Terror.	10·38	−64 16	304 42	Terror.	11·76
−55 57	305 27	Terror.	10·42	−64 18	304 18	Erebus.	11·55
−56 00	305 30	Terror.	10·51	−64 20	304 40	Terror.	11·76
−55 51	305 18	Erebus.	10·25	−64 12	303 50	Erebus.	11·97
−56 55	306 40	Terror.	10·51	−64 12	304 07	Terror.	11·74
−56 34	306 39	Erebus.	10·31	−64 08	304 00	Terror.	11·84
−57 50	307 58	Terror.	10·86	−64 16	304 47	Terror.	11·61
−58 16	308 00	Erebus.	10·54	−64 04	304 10	Terror.	11·73
−58 25	307 53	Terror.	10·74	−64 02	304 15	Terror.	11·68
−59 28	308 00	Erebus.	10·83	−64 05	304 00	Erebus.	11·60
−59 57	307 53	Terror.	10·93	−63 56	305 22	Terror.	11·61
−61 23	307 41	Erebus.	10·88	−63 30	306 59	Erebus.	11·42
−61 20	307 42	Terror.	11·16	−63 46	307 23	Erebus.	11·46
−62 12	307 47	Terror.	11·17	−63 47	308 00	Terror.	11·50
−63 31	308 05	Erebus.	11·13	−63 42	308 45	Terror.	11·49
−62 25	307 58	Terror.	11·21	−63 49	308 53	Erebus.	11·29
−62 18	308 17	Terror.	11·28	−64 19	309 40	Terror.	11·43
−62 22	308 00	Erebus.	11·15	−64 19	309 36	Erebus.	11·39
−62 30	306 52	Terror.	11·21	−64 36	311 53	Erebus.	11·36
−62 30	306 30	Erebus.	11·22	−64 43	312 06	Terror.	11·41

* On shore at St. Martin's Cove. † On shore at Port Louis. ‡ On ice.

General Table of the Intensity of the Magnetic Force (continued).

Lat.	Long.	Ship.	Intensity. British units.	Lat.	Long.	Ship.	Intensity. British units.
−64° 37′	314° 21′	Erebus.	11·29	−68° 06′	344° 40′	Erebus.	11·01
−64 38	314 01	Terror.	11·42	−68 07	346 23	Terror.	11·19
−64 39	316 04	Erebus.	11·20	−65 56	346 24	Erebus.	10·67
−64 49	315 07	Terror.	11·31	−65 57	346 40	Terror.	10·73
−64 56	317 01	Erebus.	11·08	−64 31	346 01	Erebus.	10·26
−64 47	316 57	Terror.	11·17	−63 58	346 25	Terror.	10·31
−65 06	318 46	Erebus.	11·08	−61 34	348 39	Erebus.	9·71
−64 58	318 26	Terror.	11·26	−61 35	349 00	Terror.	9·89
−64 40	320 12	Erebus.	11·02	−59 34	350 34	Erebus.	9·29
−64 37	320 28	Terror.	11·11	−59 21	350 36	Terror.	9·62
−63 54	321 36	Erebus.	10·76	−57 27	352 08	Erebus.	9·18
−64 02	321 55	Terror.	11·30	−57 31	352 04	Terror.	9·08
−63 36	324 36	Erebus.	10·69	−57 09	352 45	Erebus.	8·78
−63 59	324 18	Terror.	10·80	−57 09	352 44	Terror.	9·35
−62 39	328 16	Erebus.	10·31	−56 38	353 57	Erebus.	8·66
−62 37	328 17	Terror.	10·41	−56 44	353 45	Terror.	9·10
−62 20	330 00	Erebus.	10·21	−55 38	355 32	Erebus.	8·62
−62 13	330 28	Terror.	10·28	−54 32	357 26	Terror.	8·70
−61 59	333 43	Erebus.	10·00	−54 07	359 56	Erebus.	8·31
−62 05	333 38	Terror.	10·24	−54 05	359 33	Terror.	8·77
−61 37	336 05	Erebus.	9·95	−50 37	9 03	Erebus.	8·29
−61 32	336 10	Terror.	10·27	−50 52	8 47	Terror.	8·45
−61 30	338 00	Erebus.	9·82	−50 19	9 15	Terror.	8·52
−61 28	337 42	Terror.	10·06	−47 38	10 51	Erebus.	8·15
−61 46	341 02	Erebus.	9·80	−47 36	10 41	Terror.	8·35
−62 36	344 08	Erebus.	10·00	−45 32	11 54	Erebus.	7·96
−62 41	343 18	Terror.	10·13	−45 38	11 52	Terror.	8·14
−63 58	345 10	Erebus.	10·20	−43 57	13 16	Erebus.	7·96
−64 14	345 30	Terror.	10·42	−43 55	13 16	Terror.	7·96
−64 38	348 00	Erebus.	10·31	−43 10	14 44	Erebus.	7·83
−64 33	347 52	Terror.	10·60	−43 15	14 30	Terror.	7·96
−65 12	350 05	Erebus.	10·33	−43 11	14 43	Terror.	7·99
−65 00	349 30	Terror.	10·58	−41 48	15 09	Erebus.	7·85
−66 08	352 43	Erebus.	10·46	−41 58	15 11	Terror.	7·94
−66 00	353 00	Terror.	10·87	−40 15	15 47	Erebus.	7·71
−67 06	351 04	Erebus.	10·68	−40 12	16 06	Terror.	7·82
−66 54	351 15	Terror.	11·00	−37 40	16 40	Erebus.	7·67
−68 14	347 40	Erebus.	10·91	−38 00	16 45	Terror.	7·76
−68 08	348 10	Terror.	11·30	−35 59	16 34	Erebus.	7·59
−68 32	347 09	Erebus.	10·96	−36 04	16 32	Terror.	7·64
−69 26	345 31	Erebus.	11·17	−35 26	16 22	Erebus.	7·53
−69 24	345 30	Terror.	11·44	−35 21	16 22	Terror.	7·56
−71 10	344 13	Erebus.	11·47	−35 03	17 06	Terror.	7·63
−71 09	344 10	Terror.	11·71	−34 11	18 26	Erebus.	7·59*
−70 28	342 26	Terror.	11·70	−34 11	18 26	Terror.	7·56*

* Simon's Bay, Cape of Good Hope.

Observations of the MAGNETIC DECLINATION made on board Her Majesty's Ship 'Erebus' in 1842 and 1843, between the Falkland Islands and Cape Horn, and between Cape Horn and the Cape of Good Hope.

The Observers are distinguished as follows, viz. "R." Captain J. C. Ross; "W." Lieut. WOOD; "S." Lieut. SMITH; "O." Lieut. OAKELY; "T." Mr. TUCKER, Master; "Y." Mr. YULE, Second Master. East Declination and South Latitude are characterized by the — sign.

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1842.											
Sept. 14 P.M.	−53° 55′	304° 19′	T.	−61° 40′	S. ½ W.	−54°	+0° 06′	−1° 48′	−18° 22′	−18° 18′	
			T.	−16 01	S.	−54	−0 14	−1 48	−18 03		
			T.	−16 28	S.	−54	−0 14	−1 48	−18 30		
19 P.M.	−56 00	292 44	T.	−24 45	S.W. ½ W.	−59	+2 36	−1 48	−23 57		
Nov. 8 A.M.	−55 39	295 23	W.	−20 31	N.E. by E.	−57	−1 58	−1 48	−24 17	−24 03	
			T.	−21 28	N.E. by E.	−57	−1 58	−1 48	−25 14		
			S.	−18 42	N.E. by E.	−57	−1 58	−1 48	−22 28		
			T.	−20 27	N.E. by E.	−57	−1 58	−1 48	−24 13		
10 A.M.	−55 35	299 09	T.	−20 50	N.W. by N.	−56	+1 19	−1 48	−21 19	−20 53	
			T.	−19 39	N. by W.	−56	+0 29	−1 48	−20 58		
			T.	−19 52	N.W. by N.	−56	+1 19	−1 48	−20 21		
10 P.M.	−55 31	299 15	Y.	−19 17	N. ½ E.	−56	−0 08	−1 48	−21 13	−21 51	
			T.	−18 52	N.E.	−56	−1 31	−1 48	−22 11		
			T.	−22 56	S.W. ½ S.	−56	+2 00	−1 48	−22 44		
			T.	−22 03	S.W. by S.	−56	+1 45	−1 48	−22 06		
			T.	−21 11	S.W. ½ S.	−56	+2 00	−1 48	−20 59		
11 A.M.	−54 53	299 59	Y.	−19 33	N.	−55	+0 03	−1 48	−21 18	−21 10	
			W.	−19 17	N. ½ W.	−55	+0 15	−1 48	−20 54		
			W.	−20 54	N.	−55	+0 03	−1 48	−22 39		
			S.	−18 03	N.	−55	+0 03	−1 48	−19 48		
			T.	−19 27	N.	−55	+0 03	−1 48	−21 12		
12 A.M.	−53 04	300 51	S.	−18 03	N.	−54	+0 03	−1 48	−19 48	−19 48	
Dec. 17 P.M.	−52 04	302 47	R.	−14 09	S.E. by S.	−53	−1 54	−1 48	−17 51	−18 03	
			R.	−14 06	S.E. by S.	−53	−1 54	−1 48	−17 48		
			T.	−14 50	S.E. by S.	−53	−1 54	−1 48	−18 32		
			T.	−14 22	S.E. by S.	−53	−1 54	−1 48	−18 04		
			T.	−14 16	S.E. by S.	−53	−1 54	−1 48	−17 58		
18 A.M.	−52 50	303 12	S.	−14 51	S.E. by S.	−54	−1 57	−1 48	−18 36	−18 29	
			T.	−14 37	S.E. by S.	−54	−1 57	−1 48	−18 22		
			T.	−14 10	S.E. by S.	−54	−1 57	−1 48	−17 55		
			S.	−15 05	S.E. by S.	−54	−1 57	−1 48	−18 50		
			R.	−18 45	N.W.	−54	+1 35	−1 48	−18 58		
			T.	−14 29	S.E. by S.	−54	−1 57	−1 48	−18 14		
19 A.M.	−53 56	303 52	T.	−13 48	S.S.E.	−55	−1 31	−1 48	−17 07	−17 35	
			O.	−14 33	S.S.E.	−55	−1 31	−1 48	−17 52		
			Y.	−13 53	S.S.E.	−55	−1 31	−1 48	−17 12		
			T.	−13 59	S.S.E.	−55	−1 31	−1 48	−17 18		
			T.	−16 11	S. ½ W.	−55	+0 06	−1 48	−17 53		
			T.	−14 50	S.S.E.	−55	−1 31	−1 48	−18 09		
20 A.M.	−55 46	305 17	R.	−14 42	S.E. by S.	−55	−2 01	−1 48	−18 31	−18 47	
			T.	−15 24	S.E. by S.	−55	−2 01	−1 48	−19 13		
			S.	−14 43	S.E. by S.	−55	−2 01	−1 48	−18 32		
			Y.	−14 35	S.E. by S.	−55	−2 01	−1 48	−18 24		
			R.	−16 20	S.E. by S.	−55	−2 01	−1 48	−20 09		
			S.	−19 54	S.W. by W.	−55	+2 33	−1 48	−19 09		
			R.	−18 06	S.W. ½ W.	−55	+2 22	−1 48	−17 32		
21 A.M.	−56 36	306 38	S.	−14 56	S.S.E.	−56	−1 34	−1 48	−18 18	−17 47	
			T.	−14 22	S.S.E.	−56	−1 34	−1 48	−17 44		
			Y.	−14 32	S.S.E.	−56	−1 34	−1 48	−17 54		
			T.	−13 52	S.S.E.	−56	−1 34	−1 48	−17 14		
			T.	−14 23	S.S.E.	−56	−1 34	−1 48	−17 45		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1842.											
Dec. 21 P.M.	−56° 28′	306° 45′	T.	−18° 07′	S.S.W.	−56°	+1° 08′	−1° 48′	−18° 47′	−17° 59′	
			T.	−14 28	S. by E.	−56	−0 54	−1 48	−17 10		
22 P.M.	−58 29	308 13	T.	−14 09	S. by E. ½ E.	−57	−1 16	−1 48	−17 13	−18 02	
			R.	−14 25	S.S.E.	−57	−1 37	−1 48	−17 50		
			Y.	−15 17	S.S.E.	−57	−1 37	−1 48	−18 42		
			R.	−14 03	S.S.E.	−57	−1 37	−1 48	−17 28		
			T.	−15 36	S.S.E.	−57	−1 37	−1 48	−19 01		
			T.	−15 15	S. ½ E.	−57	−0 35	−1 48	−17 38		
			R.	−15 53	S. ¾ E.	−57	−0 45	−1 48	−18 26		
23 A.M.	−59 34	308 28	T.	−16 11	S.	−59	−0 16	−1 48	−18 15	−17 56	
			Y.	−15 00	S. by E.	−59	−0 59	−1 48	−17 47		
			T.	−15 31	S. ¼ W.	−59	−0 04	−1 48	−17 23		
			S.	−17 27	S. by W.	−59	+0 30	−1 48	−18 45		
			T.	−16 11	S. by W.	−59	+0 30	−1 48	−17 29		
27 P.M.	−62 18	308 03	O.	−18 44	S.W. by W.	−60	+3 01	−1 48	−17 31	−18 24	
			R.	−21 38	W.S.W.	−60	+3 19	−1 48	−20 07		
			R.	−18 17	S.W. by S.	−60	+2 00	−1 48	−18 05		
			R.	−18 40	S.W. by W.	−60	+3 01	−1 48	−17 27		
			Y.	−20 05	S.W. by W.	−60	+3 01	−1 48	−18 52		
28 P.M.	−62 54	305 41	R.	−23 33	S.W. ½ W.	−61	+2 54	−1 48	−22 27	−20 16	
			R.	−21 05	S.W.	−61	+2 40	−1 48	−20 13		
			R.	−20 15	S.W.	−61	+2 40	−1 48	−19 23		
			Y.	−20 39	S.W.	−61	+2 40	−1 48	−19 47		
			O.	−21 37	S.W.	−61	+2 40	−1 48	−20 45		
			O.	−19 49	S.W.	−61	+2 40	−1 48	−18 57		
			R.	−20 32	S.W.	−61	+2 40	−1 48	−19 40		
			R.	−21 51	S.W.	−61	+2 40	−1 48	−20 59		
30 P.M.	−63 40	305 00	R.	−16 59	S.E. ½ S.	−62	−2 47	−1 48	−21 34	−22 17	
			R.	−24 47	W.S.W.	−62	+3 34	−1 48	−23 01		
31 A.M.	−63 55	304 44	O.	−20 08	S.	−62	−0 17	−1 48	−22 13	−22 21	
			Y.	−20 35	E.	−62	−0 17	−1 48	−22 40		
			R.	−23 21	S.W. ½ W.	−62	+3 00	−1 48	−22 09		
1843.											
Jan. 1 A.M.	−64 14	304 21	T.	−18 42	S. ½ E.	−63	−0 42	−1 48	−21 12	−20 56	
			S.	−18 42	S. ½ E.	−63	−0 42	−1 48	−21 12		
			Y.	−21 39	W. by N. ½ N.	−63	+3 29	−1 48	−19 58		
			O.	−23 30	W. ½ N.	−63	+3 43	−1 48	−21 35		
			W.	−22 47	W. ½ S.	−63	+3 50	−1 48	−20 45		
2 A.M.	−64 26	303 52	T.	−16 53	N.E. ¼ E.	−63	−2 15	−1 48	−20 56	−22 51	
			T.	−17 51	N.E. ½ N.	−63	−1 51	−1 48	−21 30		
			T.	−19 02	N.E. ¼ E.	−63	−2 15	−1 48	−23 05		
			T.	−18 28	N.E. by E. ½ E.	−63	−2 50	−1 48	−23 06		
			R.	−20 46	E.N.E.	−63	−3 03	−1 48	−25 37		
2 P.M.	−64 35	303 47	W.	−20 22	E.N.E.	−63	−3 03	−1 48	−25 13	−23 51	
			R.	−20 17	E.N.E.	−63	−3 03	−1 48	−25 08		
			R.	−19 38	E. by N.	−63	−3 23	−1 48	−24 49		
			R.	−23 42	N.W.	−63	+2 26	−1 48	−23 04		
			R.	−23 02	N.W.	−63	+2 26	−1 48	−22 24		
			T.	−24 13	W. by N. ¼ N.	−63	+3 34	−1 48	−22 27		
	−64 26	303 52	T.	−20 50	On ice ……	−63	……	………	…………	−20 50	
			T.	−20 49	On ice ……	−63					
4 A.M.	−64 34	304 20	T.	−19 38	S.	−63	−0 17	−1 48	−21 43	−21 50	
			Y.	−19 15	S.	−63	−0 17	−1 48	−21 20		
			W.	−19 52	S.	−63	−0 17	−1 48	−21 57		
			T.	−17 38	S.S.E.	−63	−1 57	−1 48	−21 23		
			T.	−17 51	S.S.E.	−63	−1 57	−1 48	−21 36		
			S.	−18 24	S.S.E.	−63	−1 57	−1 48	−22 09		
4 P.M.	−64 37	304 21	R.	−17 35	E. by N. ¼ N.	−63	−3 18	−1 48	−22 41		
5 A.M.	−64 20	304 28	S.	−21 18	W. ½ S.	−63	+3 50	−1 48	−19 16	−19 19	
			T.	−21 44	W. by S.	−63	+3 51	−1 48	−19 41		
			O.	−20 50	W. by N.	−63	+3 38	−1 48	−19 00		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination		Remarks.
							Deviation.	Index.			
1843.											
Jan. 5 P.M.	−64° 04′	304° 41′	W.	−21° 26′	S.W. by W. ½ W.	−63°	+3° 33′	−1° 48′	−19° 41′	−20° 44′	
			T.	−22 42	S.W. by W. ½ W.	−63	+3 33	−1 48	−20 57		
			T.	−22 16	S.W. by S.	−63	+2 13	−1 48	−21 51		
			W.	−20 06	S.S.W.	−63	+1 26	−1 48	−20 28		
6 A.M.	−64 09	303 03	O.	−17 46	S.E. by S.	−63	−2 38	−1 48	−22 12	−21 32	
			T.	−17 05	S.E. by E.	−63	−3 32	−1 48	−22 25		
			T.	−18 02	S. by E.	−63	−1 08	−1 48	−20 58		
			W.	−18 04	S. ½ E.	−63	−0 42	−1 48	−20 34		
7 A.M.	−64 30	303 0	W.	−18 38	S.S.E. ½ E.	−63	−2 18	−1 48	−22 44	−23 00	
			T.	−19 51	S.S.E.	−63	−1 57	−1 48	−23 36		
			T.	−24 30	W. by N.	−63	+3 38	−1 48	−22 40		
9 A.M.	−64 44	303 10	W.	−21 58	N.W. ½ N.	−63	+2 13	−1 48	−21 33	−22 03	
9 P.M.	−64 44	303 15	R.	−20 52	S. ½ W.	−63	+0 08	−1 48	−22 32		
			T.	−19 15	S.S.E.	−63	−1 57	−1 48	−23 00		
			T.	−19 10	S. ¼ E.	−63	−0 30	−1 48	−21 28		
			W.	−19 04	S. by E.	−63	−1 08	−1 48	−22 00		
			T.	−18 21	S. by E. ½ E.	−63	−1 32	−1 48	−21 41		
			R.	−17 08	S.E. ½ S.	−63	−2 54	−1 48	−21 50		
			T.	−17 20	S.E.	−63	−3 10	−1 48	−22 18		
	−64 44	303 10	R.	−18 49	On ice …	……	………	−0 44	−21 13	−21 13	Mean of three compasses.
			R.	−21 12							
			R.	−21 26							
10 A.M.	−64 42	303 10	S.	−19 20	S.S.E. ½ E.	−63	−2 18	−1 48	−23 26	−22 55	
10 P.M.	……	……	W.	−19 28	S. by E.	−63	−1 08	−1 48	−22 24		
11 A.M.	−64 38	303 02	T.	−18 15	E.S.E.	−63	−3 44	−1 48	−23 47	−23 57	
			T.	−18 24	E.S.E.	−63	−3 44	−1 48	−23 56		
			O.	−18 36	E.S.E.	−63	−3 44	−1 48	−24 08		
12 P.M.	−64 39	302 36	T.	−19 58	S.S.E.	−63	−1 57	−1 48	−23 43	−23 04	
			R.	−19 52	S.S.E.	−63	−1 57	−1 48	−23 37		
			T.	−25 24	W. by N.	−63	+3 38	−1 48	−23 34		
			T.	−18 18	S.S.E. ½ E.	−63	−2 18	−1 48	−22 24		
			T.	−24 01	W. by S. ½ S.	−63	+3 47	−1 48	−22 02		
	−64 39	302 36	R.	−19 18	On ice ……	……	………	−2 56	−22 14	−22 14	Kater's compass.
13 A.M.	−64 36	302 38	W.	−22 24	N.W. ½ N.	−63	+2 09	−1 48	−22 03	−23 11	
			W.	−19 13	S.S.E. ½ E.	−63	−2 18	−1 48	−23 19		
			Y.	−19 17	S.E. by E.	−63	−3 32	−1 48	−24 37		
			T.	−19 04	S.E. ½ S.	−63	−2 54	−1 48	−23 46		
			S.	−21 15	S. ½ E.	−63	−0 42	−1 48	−23 45		
			S.	−22 15	N.W. by N.	−63	+1 52	−1 48	−22 11		
			T.	−22 59	N.W. ½ N.	−63	+2 13	−1 48	−22 34		
14 A.M.	−64 31	302 36	Y.	−26 28	W. ½ S.	−64	+4 00	−1 48	−24 36	−24 27	
			T.	−26 09	W.	−64	+3 59	−1 48	−24 18		
15 A.M.	−64 31	302 36	O.	−25 42	W. ½ N.	−63	+3 43	−1 48	−23 47	−22 48	
			W.	−16 20	E. ½ S.	−63	−3 42	−1 48	−21 50		
18 A.M.	−63 58	304 46	Y.	−17 32	N.N.E.	−63	−1 02	−1 48	−20 22	−20 22	
19 P.M.	−64 28	304 46	R.	−22 58	W.S.W.	−63	+3 43	−1 48	−21 03	−21 25	
			T.	−17 47	N.E. by E.	−63	−2 37	−1 48	−22 12		
			R.	−21 52	W.N.W.	−63	+3 20	−1 48	−20 20		
			T.	−22 34	N.W. by W.	−63	+2 54	−1 48	−21 28		
			W.	−23 23	N.W. by W.	−63	+2 54	−1 48	−22 17		
			R.	−22 51	W. by N.	−63	+3 38	−1 48	−21 01		
			T.	−23 35	W. ½ S.	−63	+3 50	−1 48	−21 33		
20 A.M.	−64 19	304 30	T.	−17 30	E. by S. ½ S.	−63	−3 44	−1 48	−23 02	−22 03	
			T.	−17 08	S.E.	−63	−3 10	−1 48	−22 06		
			T.	−16 48	S.E. by E. ½ E.	−63	−3 38	−1 48	−22 14		
			T.	−23 26	W. by N.	−63	+3 38	−1 48	−21 36		
			O.	−23 18	W. ½ S.	−63	+3 50	−1 48	−21 16		
21 P.M.	−64 18	304 10	T.	−16 32	S.E. by S.	−63	−2 38	−1 48	−20 58	−21 28	
			W.	−17 34	S.E.	−63	−3 10	−1 48	−22 32		
			O.	−15 45	S.E. ½ E.	−63	−3 21	−1 48	−20 54		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843. Jan. 22 A.M.	−64° 15′	303° 49′	W.	−22° 27′	W. by N.	−62°	+3° 30′	−1° 48′	−20° 45′	−21° 03′	
			W.	−21 18	N.W. by W.	−62	+2 46	−1 48	−20 20		
			T.	−17 02	E.N.E.	−62	−2 54	−1 48	−21 44		
			S.	−15 46	S.E. ½ S.	−62	−2 47	−1 48	−20 21		
			S.	−15 40	E. ½ N.	−62	−3 21	−1 48	−20 49		
			Y.	−16 20	N.E. by E.	−62	−2 29	−1 48	−20 37		
			T.	−16 34	E.	−62	−3 30	−1 48	−21 52		
			S.	−17 08	E.N.E.	−62	−2 54	−1 48	−21 50		
23 A.M.	−64 12	303 53	T.	−22 37	W. by N.	−63	+3 38	−1 48	−20 47	−20 39	
			Y.	−21 48	N.W. ½ W.	−63	+2 40	−1 48	−20 56		
			T.	−21 36	N.W.byW.½W.	−63	+3 07	−1 48	−20 17		
26 A.M.	−64 04	304 18	T.	−22 48	W. ½ S.	−63	+3 50	−1 48	−20 46	−20 50	
			T.	−22 03	W.N.W.	−63	+3 20	−1 48	−20 31		
			O.	−21 57	W.N.W.	−63	+3 20	−1 48	−20 25		
			T.	−17 10	S.E. by S.	−63	−2 38	−1 48	−21 36		
26 P.M.	−64 04	304 18	R.	−15 25	S.E. ½ E.	−63	−3 21	−1 48	−20 34	−20 48	
			T.	−22 10	W.	−63	+3 49	−1 48	−20 09		
			W.	−16 04	S.E. by E.	−63	−3 32	−1 48	−21 24		
			T.	−15 21	S.E. ½ E.	−63	−3 21	−1 48	−20 30		
			R.	−22 54	S.W.byW.½W.	−63	+3 33	−1 48	−21 09		
			T.	−22 22	W.S.W.	−63	+3 43	−1 48	−20 27		
			R.	−15 53	E.S.E.	−63	−3 44	−1 48	−21 25		
27 P.M.	−64 08	304 14	T.	−19 00	S.	−63	−0 17	−1 48	−21 05	−20 55	
			R.	−16 33	N.E. ½ N.	−63	−1 50	−1 48	−20 11		
			T.	−19 50	S. ½ W.	−63	+0 08	−1 48	−21 30		
28 A.M.	−64 08	304 03	Y.	−16 09	E.S.E.	−63	−3 44	−1 48	−21 41	−21 41	
29 A.M.	−64 04	303 58	T.	−16 59	S.E. ½ E.	−63	−3 21	−1 48	−22 08	−21 37	
			T.	−16 48	S.E.	−63	−3 10	−1 48	−21 46		
			Y.	−16 58	S.E. ½ E.	−63	−3 21	−1 48	−22 07		
			T.	−22 08	W.N.W.	−63	+3 20	−1 48	−20 36		
			T.	−20 36	N. by W.	−63	+0 43	−1 48	−21 41		
			W.	−20 15	N. by W.	−63	+0 43	−1 48	−21 20		
31 P.M.	−64 08	303 47	R.	−22 29	N.W. ¼ W.	−62	+2 26	−1 48	−21 51	−21 52	
			R.	−17 59	N.E.by E.¾E.	−62	−2 36	−1 48	−22 23		
			T.	−17 05	N.E. ½ N.	−62	−1 46	−1 48	−20 39		
			W.	−17 47	E.N.E.	−62	−2 54	−1 48	−22 29		
			R.	−23 26	N.W.	−62	+2 19	−1 48	−22 55		
			T.	−18 18	N.E. by N.	−62	−1 30	−1 48	−21 36		
			T.	−21 43	S.W. by W.	−62	+3 15	−1 48	−20 16		
			R.	−24 55	W. by N. ½ N.	−62	+3 20	−1 48	−23 23		
			T.	−20 01	N. by E.	−62	−0 27	−1 48	−22 16		
			R.	−22 47	W. by N.	−62	+3 30	−1 48	−21 05		
			R.	−16 38	E. ¼ N.	−62	−3 26	−1 48	−21 52		
			T.	−19 21	N. by E.	−62	−0 27	−1 48	−21 36		
Feb. 1 A.M.	−63 53	304 01	T.	−21 30	S.W. ½ S.	−62	+2 27	−1 48	−20 51	−20 36	
			S.	−21 24	S.W. by S.	−62	+2 08	−1 48	−21 04		
			Y.	−21 02	S.S.W. ½ W.	−62	+1 47	−1 48	−21 03		
			T.	−21 00	N.N.W. ½ W.	−62	+1 30	−1 48	−21 18		
			Y.	−20 08	N.N.W. ½ W.	−62	+1 30	−1 48	−20 26		
			T.	−21 03	N.W. by W.	−62	+2 46	−1 48	−20 05		
			T.	−21 43	W. ½ S	−62	+3 41	−1 48	−19 50		
			W.	−22 04	W. by S.	−62	+3 42	−1 48	−20 10		
3 A.M.	−64 16	305 23	T.	−19 16	N. ½ E.	−62	−0 10	−1 48	−21 14	−20 37	
			T.	−17 53	N. by E.	−62	−0 27	−1 48	−20 08		
			T.	−18 22	N. by E. ¼ E.	−62	−0 35	−1 48	−20 45		
			T.	−18 56	N. ½ W.	−62	+0 23	−1 48	−20 21		
12 A.M.	−64 44	315 41	Y.	−10 03	S. by E. ½ E.	−61	−1 26	−1 48	−13 17	−13 58	
			T.	−10 57	S. by E. ½ E.	−61	−1 26	−1 48	−14 11		
			W.	−11 05	S. by E. ½ E.	−61	−1 26	−1 48	−14 19		
			T.	−11 55	N. ¾ E.	−61	−0 21	−1 48	−14 04		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843. Feb. 12 P.M.	−64° 13′	316° 22′	R.	− 9° 52′	N.E. ½ E.	−61°	−2° 09′	−1° 48′	−13° 49′	−13° 43′	
			R.	− 8 34	E.N.E.	−61	−2 46	−1 48	−13 08		
			R.	−10 27	N.E.	−61	−1 56	−1 48	−14 11		
13 A.M.	−64 38	316 47	T.	−11 47	N. by E.	−62	−0 27	−1 48	−14 02	−13 46	
			S.	−12 43	N. by E.	−62	−0 27	−1 48	−14 58		
			T.	−10 12	S.S.E.	−62	−1 53	−1 48	−13 53		
			T.	−10 30	S.S.E.	−62	−1 53	−1 48	−14 11		
			S.	−10 48	S.S.E.	−62	−1 53	−1 48	−14 29		
			T.	− 9 11	S.S.E.	−62	−1 53	−1 48	−12 52		
			O.	− 8 59	S.S.E.	−62	−1 53	−1 48	−12 40		
			Y.	− 9 31	S.S.E.	−62	−1 53	−1 48	−13 12		
			R.	− 8 21	S.E. by E.	−62	−3 24	−1 48	−13 33		
13 P.M.	−64 48	316 54	R.	−12 39	N. ½ W.	−62	+0 23	−1 48	−14 04	−13 49	
			R.	−11 51	N. ½ W.	−62	+0 23	−1 48	−13 16		
			T.	− 8 54	S.E. by E.	−62	−3 24	−1 48	−14 06		
14 A.M.	−65 06	318 57	O.	− 9 04	E.	−62	−3 30	−1 48	−14 22	−13 20	
			Y.	− 9 00	E.	−62	−3 30	−1 48	−14 18		
			T.	− 7 33	E. by S.	−62	−3 36	−1 48	−12 57		
			W.	− 8 08	E. ½ N.	−62	−3 21	−1 48	−13 17		
			T.	− 7 45	E. ½ N.	−62	−3 21	−1 48	−12 54		
			T.	− 7 27	E. ½ N.	−62	−3 21	−1 48	−12 36		
14 P.M.	−65 13	319 20	R.	− 7 23	E. ¾ S.	−61	−3 26	−1 48	−12 37	−12 47	
			R.	− 7 39	S.E. by E.	−61	−3 17	−1 48	−12 44		
			R.	−10 45	N. by E.	−61	−0 26	−1 48	−12 59		
15 A.M.	−63 57	321 37	T.	− 7 06	N.E.	−60	−1 50	−1 48	−10 44	− 8 59	
16 A.M.	−63 56	321 43	Y.	− 6 50	N.E.	−60	−1 50	−1 48	−10 28		
			T.	− 5 42	N.E. ½ N.	−60	−1 36	−1 48	− 9 06		
			T.	− 6 43	S. ¾ W.	−60	+0 19	−1 48	− 8 12		
			R.	− 6 33	S.	−60	−0 16	−1 48	− 8 37		
			R.	− 3 37	E. ¼ N.	−60	−3 09	−1 48	− 8 34		
16 P.M.	−63 56	322 14	R.	− 3 19	E. ¼ N.	−60	−3 09	−1 48	− 8 16	− 9 24	
			W.	− 4 08	E. ½ S.	−60	−3 17	−1 48	− 9 13		
			T.	− 4 34	E. ½ N.	−60	−3 05	−1 48	− 9 27		
			R.	− 5 38	E.	−60	−3 13	−1 48	−10 39		
18 A.M.	−62 50	328 20	R.	− 3 14	E. ½ N.	−59	−2 57	−1 48	− 7 59	− 7 54	
			T.	− 3 00	E. ½ N.	−59	−2 57	−1 48	− 7 45		
			S.	− 3 21	E. by N.	−59	−2 50	−1 48	− 7 59		
18 P.M.	−62 37	328 30	T.	− 0 23	E. ¼ S.	−59	−3 07	−1 48	− 5 18	− 2 50	
			R.	+ 1 12	N.E. ½ E.	−59	−1 57	−1 48	− 2 33		
			T.	+ 1 48	N.E. by E. ½ E.	−59	−2 20	−1 48	− 2 20		
			T.	+ 1 45	N.E.	−59	−1 45	−1 48	− 1 48		
			T.	+ 0 45	E. by N. ½ N.	−59	−2 41	−1 48	− 3 44		
			T.	+ 1 37	E. by N. ½ N.	−59	−2 41	−1 48	− 2 52		
			T.	+ 0 52	N.E. by E. ½ E.	−59	−2 20	−1 48	− 3 16		
19 A.M.	−62 20	330 30	S.	− 3 49	N.E.	−58	−1 40	−1 48	− 7 17	− 4 41	
			T.	− 0 25	E.	−58	−2 58	−1 48	− 5 11		
			O.	− 0 11	E.	−58	−2 58	−1 48	− 4 57		
			S.	+ 1 20	E.	−58	−2 58	−1 48	− 3 26		
			R.	+ 2 45	E.	−58	−2 58	−1 48	− 2 01		
			T.	0 00	E. ½ S.	−58	−3 01	−1 48	− 4 49		
			R.	− 0 54	E. by S.	−58	−3 05	−1 48	− 5 47		
			T.	+ 0 51	E.S.E.	−58	−3 05	−1 48	− 4 02		
20 A.M.	−62 06	333 43	T.	+ 0 35	S.E. by E. ½ E.	−58	−3 00	−1 48	− 4 13	− 3 41	
			O.	− 0 58	N.N.E. ¾ E.	−58	−1 07	−1 48	− 3 53		
			T.	− 2 14	N.	−58	+0 06	−1 48	− 3 56		
			O.	− 1 53	N. by E. ½ E.	−58	−0 35	−1 48	− 4 16		
			T.	− 0 46	N.N.E.	−58	−0 48	−1 48	− 3 22		
			W.	− 0 48	N. by E. ½ E.	−58	−0 35	−1 48	− 3 11		
			T.	− 1 18	N.	−58	+0 06	−1 48	− 3 00		
			R.	+ 0 17	N.E. by E.	−58	−2 03	−1 48	− 3 34		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843.											
Feb. 20 P.M.	−61° 55′	333° 48′	S.	− 1° 05′	N.E. by N.	−58°	−1° 14′	−1° 48′	− 4° 07′	− 3° 38′	
			R.	− 0 30	N.N.E.	−58	−0 48	−1 48	− 3 06		
			R.	− 0 23	N. by E.	−58	−0 23	−1 48	− 2 34		
			R.	− 1 01	N. by E. ¾ E.	−58	−0 42	−1 48	− 3 31		
			R.	− 1 58	N. by E. ½ E.	−58	−0 35	−1 48	− 4 21		
			R.	− 0 15	N.E.	−58	−1 40	−1 48	− 3 43		
			Y.	− 1 00	N.E.	−58	−1 40	−1 48	− 4 28		
			T.	− 0 26	N.E.	−58	−1 40	−1 48	− 3 54		
			T.	− 0 16	N.E.	−58	−1 40	−1 48	− 3 44		
			O.	− 0 32	N.E.	−58	−1 40	−1 48	− 4 00		
			R.	− 0 41	N.E.	−58	−1 40	−1 48	− 4 09		
			T.	− 0 28	N.E.	−58	−1 40	−1 48	− 3 56		
			R.	− 0 55	S. ½ E.	−58	−0 36	−1 48	− 3 19		
			T.	− 1 00	S. ½ E.	−58	−0 36	−1 48	− 3 24		
			R.	− 1 28	S. ½ W.	−58	+0 07	−1 48	− 3 09		
			R.	− 1 46	S. by W. ½ W.	−58	+0 51	−1 48	− 2 43		
21 P.M.	−61 36	336 20	R.	+ 5 15	E. ¼ S.	−58	−3 00	−1 48	+ 0 27	− 0 44	
			O.	+ 3 39	E.	−58	−2 58	−1 48	− 1 07		
			S.	+ 4 47	E. ½ S.	−58	−3 01	−1 48	− 0 02		
			T.	+ 4 02	E. ½ S.	−58	−3 01	−1 48	− 0 47		
			R.	+ 3 30	E.	−58	−2 58	−1 48	− 1 16		
			T.	+ 4 32	E.	−58	−2 58	−1 48	− 0 14		
			R.	+ 4 12	E. ¼ N.	−58	−2 54	−1 48	− 0 30		
			R.	+ 2 24	E. ½ N.	−58	−2 51	−1 48	− 2 15		
			Y.	+ 0 52	S. ½ W.	−58	+0 06	−1 48	− 0 50		
			R.	+ 0 59	S. ½ W.	−58	+0 06	−1 48	− 0 43		
24 A.M.	−62 24	343 58	W.	+ 5 21	S.	−59	−0 16	−1 48	+ 3 17	+ 4 40	
			T.	+ 6 01	S.	−59	−0 16	−1 48	+ 3 37		
			T.	+ 7 37	S. by E.	−59	−0 59	−1 48	+ 4 50		
			S.	+ 7 36	S.	−59	−0 16	−1 48	+ 5 32		
			T.	+ 7 00	S. ½ W.	−59	+0 06	−1 48	+ 5 18		
			Y	+ 6 40	S. ½ W.	−59	+0 06	−1 48	+ 4 58		
			T.	+ 7 57	S. ¼ E.	−59	−0 26	−1 48	+ 5 43		
			S.	+ 7 51	S. by E.	−59	−0 59	−1 48	+ 5 04		
24 P.M.	−62 52	344 33	T.	+ 6 48	S. ½ E.	−59	−0 36	−1 48	+ 4 24	+ 4 40	
			T.	+ 7 31	S. ½ E.	−59	−0 36	−1 48	+ 5 07		
			T.	+ 7 14	S. ½ E.	−59	−0 36	−1 48	+ 4 50		
			Y.	+ 6 25	S. ½ E.	−59	−0 36	−1 48	+ 4 01		
			W.	+ 7 24	S. ½ E.	−59	−0 36	−1 48	+ 5 00		
			R.	+ 6 31	S. ½ W.	−59	+0 06	−1 48	+ 4 49		
			T.	+ 6 31	S.	−59	−0 16	−1 48	+ 4 27		
25 A.M.	−64 04	345 16	T.	+ 8 07	S.S.E.	−60	−1 46	−1 48	+ 4 33	+ 5 03	
			Y.	+ 9 04	S.S.E. ½ E.	−60	−2 04	−1 48	+ 5 12		
			T.	+ 7 50	S. by E. ½ E.	−60	−1 23	−1 48	+ 4 39		
			T.	+ 8 59	S. by E. ½ E.	−60	−1 23	−1 48	+ 5 48		
27 A.M.	−65 08	349 50	T.	+11 13	S.E.	−62	−3 03	−1 48	+ 6 22	+ 7 02	
			W.	+12 26	S.E.	−62	−3 03	−1 48	+ 7 35		
			T.	+11 21	S.E.	−62	−3 03	−1 48	+ 6 30		
			R.	+12 11	S.E.	−62	−3 03	−1 48	+ 7 20		
			S.	+12 03	S.E.	−62	−3 03	−1 48	+ 7 12		
			T.	+11 53	S.E.	−62	−3 03	−1 48	+ 7 02		
			R.	+12 05	S.E.	−62	−3 03	−1 48	+ 7 14		
28 A.M.	−66 01	353 00	R.	+14 43	E. by S. ½ S.	−63	−3 44	−1 48	+ 9 11	+ 9 06	
			T.	+14 42	E. by S. ½ S.	−63	−3 44	−1 48	+ 9 10		
			R.	+13 53	E.S.E.	−63	−3 44	−1 48	+ 8 21		
			O.	+14 39	E. ½ S.	−63	−3 41	−1 48	+ 9 10		
			T.	+15 07	E. ½ S.	−63	−3 41	−1 48	+ 9 38		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843.											
Mar. 1 A.M.	−66° 40′	350° 39′	R.	+ 6° 52′	S.W. ¾ W.	−63°	+2° 23′	−1° 48′	+ 7° 27′	+ 8° 56′	
1 P.M.	....	....	T.	+ 7 16	W.S.W.	−63	+3 43	−1 48	+ 9 11		
			R.	+ 7 07	W.S.W.	−63	+3 43	−1 48	+ 9 02		
			R.	+ 7 58	W.S.W.	−63	+3 43	−1 48	+ 9 53		
			Y.	+ 6 42	W.S.W.	−63	+3 43	−1 48	+ 8 37		
			T.	+ 7 56	S.W.	−63	+2 52	−1 48	+ 9 00		
			O.	+ 8 18	S.W.	−63	+2 52	−1 48	+ 9 22		
2 A.M.	−68 00	348 21	T.	+ 4 41	S.W. by W.	−64	+3 31	−1 48	+ 6 24	+ 6 34	
			Y.	+ 5 01	S.W. by W.	−64	+3 31	−1 48	+ 6 44		
			T.	+ 4 59	S.W. by W.	−64	+3 31	−1 48	+ 6 42		
			Y.	+ 5 14	S.W.	−64	+2 58	−1 48	+ 6 24		
			S.	+ 5 12	S.W.	−64	+2 58	−1 48	+ 6 22		
			T.	+ 4 51	S.W.	−64	+2 58	−1 48	+ 6 01		
			T.	+ 5 34	S.W.	−64	+2 58	−1 48	+ 6 44		
2 P.M.	−68 18	347 20	T.	+ 4 10	S.W. ½ W.	−64	+3 14	−1 48	+ 5 36	+ 5 37	
			O.	+ 4 04	S.W. by W. ½ W.	−64	+3 41	−1 48	+ 5 57		
			T.	+ 4 24	S.W. ½ W.	−64	+3 14	−1 48	+ 5 50		
			R.	+ 3 42	S.W. ½ W.	−64	+3 14	−1 48	+ 5 08		
			R.	+ 3 59	S.W. ½ W.	−64	+3 14	−1 48	+ 5 25		
			T.	+ 5 13	S.W.	−64	+2 58	−1 48	+ 6 23		
			R.	+ 3 47	S.W.	−64	+2 58	−1 48	+ 4 57		
3 A.M.	−68 32	347 09	T.	+ 7 41	S.S.E.	−64	−2 02	−1 48	+ 3 51	+ 4 43	
			Y.	+ 8 07	S. ½ E.	−64	−0 45	−1 48	+ 5 34		
4 P.M.	−69 36	345 18	T.	+ 3 00	S.W. by S.	−65	+2 24	−1 48	+ 3 36	+ 3 05	
			R.	+ 2 28	S.W. by S.	−65	+2 24	−1 48	+ 3 04		
			R.	+ 2 08	S.W. by S.	−65	+2 24	−1 48	+ 2 44		
			T.	+ 2 19	S.W. by S.	−65	+2 24	−1 48	+ 2 55		
5 A.M.	−70 50	343 21	Y.	+ 1 25	S.W. by S.	−66	+2 30	−1 48	+ 2 07	+ 2 18	
			T.	+ 1 55	S.W. by S.	−66	+2 30	−1 48	+ 2 37		
			T.	+ 4 18	S.	−66	−0 19	−1 48	+ 2 11		
			R.	+ 6 25	S.S.E.	−66	−2 12	−1 48	+ 2 25		
			T.	+ 6 04	S.S.E.	−66	−2 12	−1 48	+ 2 04		
5 P.M.	....	....	R.	+ 8 22	S.E. by E.	−66	−4 00	−1 48	+ 2 34		
8 P.M.	−71 14	344 18	R.	+ 8 40	E.S.E.	−65	−4 04	−1 48	+ 2 48	+ 3 23	
			R.	+ 9 50	E.S.E.	−65	−4 04	−1 48	+ 3 58		
12 A.M.	−64 29	346 02	T.	+ 6 50	N.N.E.	−59	−0 51	−1 48	+ 4 11	+ 4 25	
			S.	+ 7 04	N.N.E.	−59	−0 51	−1 48	+ 4 25		
			T.	+ 7 33	N.N.E.	−59	−0 51	−1 48	+ 4 54		
			T.	+ 6 48	N.N.E.	−59	−0 51	−1 48	+ 4 09		
13 P.M.	−61 16	348 56	T.	+12 31	N.N.E. ½ E.	−58	−1 01	−1 48	+ 9 42	+ 8 59	
			R.	+12 22	N.E. ½ N.	−58	−1 27	−1 48	+ 9 07		
			T.	+11 26	N.E. by N.	−58	−1 10	−1 48	+ 8 28		
			T.	+11 37	N.E. by N.	−58	−1 10	−1 48	+ 8 39		
15 A.M.	−57 46	351 52	T.	+14 08	N.E. by N.	−57	−1 10	−1 48	+11 10	+11 17	
			S.	+14 13	N.E. by N.	−57	−1 10	−1 48	+11 15		
			O.	+14 17	N.E. by N.	−57	−1 10	−1 48	+11 19		
			T.	+13 46	N.E. by N.	−57	−1 10	−1 48	+10 48		
			S.	+14 49	N.E. by N.	−57	−1 10	−1 48	+11 51		
15 P.M.	−57 22	352 12	R.	+15 39	N.E.	−57	−1 35	−1 48	+12 16	+13 10	
			T.	+15 35	N.E.	−57	−1 35	−1 48	+12 12		
			R.	+16 46	N.E.	−57	−1 35	−1 48	+13 23		
			T.	+15 59	N.E.	−57	−1 35	−1 48	+12 36		
			R.	+17 05	N.E.	−57	−1 35	−1 48	+13 42		
			Y.	+17 11	N.E.	−57	−1 35	−1 48	+13 48		
			T.	+17 34	N.E.	−57	−1 35	−1 48	+14 11		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843. Mar. 16 A.M.	−57° 10′	352° 53′	T.	+13° 13′	N.N.W.	−56°	+0° 54′	−1° 48′	+12° 19′	+12° 28′	
			O.	+12 47	N.N.W.	−56	+0 54	−1 48	+11 53		
			Y.	+14 01	N.N.W.	−56	+0 54	−1 48	+13 07		
			T.	+13 50	N. by W. ½ W.	−56	+0 41	−1 48	+12 43		
			T.	+13 31	N. by W. ½ W.	−56	+0 41	−1 48	+12 24		
			R.	+13 18	N. by W. ½ W.	−56	+0 41	−1 48	+12 11		
			R.	+13 35	N.N.W.	−56	+0 54	−1 48	+12 41		
			R.	+13 01	N.W. by N.	−56	+1 19	−1 48	+12 32		
16 P.M.	−57 04	352 52	R.	+19 04	E.N.E.	−56	−2 13	−1 48	+15 03	+14 57	
			Y.	+19 20	E.N.E.	−56	−2 13	−1 48	+15 19		
			T.	+19 01	E.N.E.	−56	−2 13	−1 48	+15 00		
			T.	+18 50	E. ½ N.	−56	−2 37	−1 48	+14 25		
17 P.M.	−56 34	353 46	R.	+17 31	N.E. by E. ¾ E.	−56	−1 58	−1 48	+13 45	+13 46	
			T.	+17 23	N.E. by E.	−56	−1 53	−1 48	+13 42		
			R.	+17 32	N.E. by E.	−56	−1 53	−1 48	+13 51		
18 A.M.	−55 58	355 32	T.	+17 35	E. by N.	−56	−2 30	−1 48	+13 17	+13 21	
			R.	+17 26	E. ½ N.	−56	−2 37	−1 48	+13 01		
			O.	+18 11	E. ½ N.	−56	−2 37	−1 48	+13 46		
18 P.M.	−55 53	355 44	R.	+17 39	E. ½ N.	−56	−2 37	−1 48	+13 14	+13 14	
19 A.M.	−54 28	357 45	T.	+20 49	E. by N.	−56	−2 30	−1 48	+16 31	+16 48	
			T.	+21 24	E. by N.	−56	−2 30	−1 48	+17 06		
20 A.M.	−54 06	359 38	T.	+21 23	S.E. by E.	−56	−2 45	−1 48	+16 50	+17 11	
			Y.	+22 16	S.E. by E.	−56	−2 45	−1 48	+17 43		
			T.	+22 00	S.E. by E.	−56	−2 45	−1 48	+17 27		
			R.	+22 21	S.E. by E.	−56	−2 45	−1 48	+17 48		
			T.	+21 15	S.E. by E.	−56	−2 45	−1 48	+16 42		
			O.	+21 11	S.E. by E.	−56	−2 45	−1 48	+16 38		
24 P.M.	−50 00	9 35	T.	+28 10	N.E.	−56	−1 31	−1 48	+24 51	+24 12	
			R.	+26 40	N.E.	−56	−1 31	−1 48	+23 21		
			R.	+26 52	N.E.	−56	−1 31	−1 48	+23 33		
			T.	+28 22	N.E.	−56	−1 31	−1 48	+25 03		
25 A.M.	−48 20	10 44	T.	+29 33	N.E.	−56	−1 31	−1 48	+26 14	+25 35	
			O.	+28 15	N.E.	−56	−1 31	−1 48	+24 56		
25 P.M.	−47 20	11 04	R.	+28 51	N.E.	−56	−1 31	−1 48	+25 32	+25 22	
			T.	+29 30	N.E.	−56	−1 31	−1 48	+26 11		
			R.	+27 43	N.E.	−56	−1 31	−1 48	+24 24		
27 P.M.	−43 49	13 38	R.	+33 43	E. by N. ½ N.	−55	−2 15	−1 48	+29 40	+29 28	
			T.	+33 58	E. by N. ½ N.	−55	−2 15	−1 48	+29 55		
			T.	+32 53	E. by N. ½ N.	−54	−2 15	−1 48	+28 50		
28 A.M.	−43 17	14 34	T.	+32 36	E. by N. ½ N.	−55	−2 15	−1 48	+28 38	+28 18	
			T.	+31 56	E. by N. ½ N.	−55	−2 15	−1 48	+27 58		
28 P.M.	−43 03	14 50	R.	+30 45	N.E.	−54	−1 23	−1 48	+27 34	+28 32	
			T.	+30 43	N.E.	−54	−1 23	−1 48	+27 32		
			T.	+31 37	N.E. ½ E.	−54	−1 33	−1 48	+28 16		
			T.	+31 44	N.E. by E.	−54	−1 43	−1 48	+28 13		
			T.	+31 09	N.E. by N.	−54	−1 01	−1 48	+28 20		
			R.	+31 22	N.E.	−54	−1 23	−1 48	+28 11		
			R.	+32 06	N.E.	−54	−1 23	−1 48	+28 55		
			R.	+33 43	N.E.	−54	−1 23	−1 48	+30 32		
			R.	+32 16	N.E. ½ N.	−54	−1 12	−1 48	+29 16		
29 A.M.	−41 56	15 07	S.	+30 22	N.E. ½ N.	−54	−1 12	−1 48	+27 22	+27 42	
			T.	+30 58	N.E. ½ N.	−54	−1 12	−1 48	+27 58		
			R.	+30 35	N.E. by N.	−54	−1 01	−1 48	+27 46		
29 P.M.	−41 30	15 14	R.	+32 09	N.E ½ N.	−54	−1 12	−1 48	+29 09	+30 01	
			T.	+33 07	N.E. ½ N.	−54	−1 12	−1 48	+30 07		
			R.	+34 23	N.E. ½ N.	−54	−1 12	−1 48	+31 23		
			R.	+32 25	N.E. ½ N.	−54	−1 12	−1 48	+29 25		

Observations of Declination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Observers.	Declination observed.	Ship's head.	Approximate Inclination.	Corrections.		True Declination.		Remarks.
							Deviation.	Index.			
1843. Mar. 30 P.M.	−39° 43′	15° 45′	T.	+32° 30′	E.S.E.	−54°	−2° 41′	−1° 48′	+28° 01′	+28° 29′	
			T.	+32 10	N.E.	−54	−1 23	−1 48	+28 59		
			R.	+31 53	N.E.	−54	−1 23	−1 48	+28 42		
			R.	+32 03	N.E. ½ E.	−54	−1 33	−1 48	+28 42		
			R.	+31 34	N.E. by E.	−54	−1 43	−1 48	+28 03		
31 A.M.	−37 50	16 35	T.	+32 00	N.E. ½ E.	−54	−1 33	−1 48	+28 39	+29 28	
			T.	+33 48	N.E. by E.	−54	−1 43	−1 48	+30 17		
April 1 A.M.	−36 36	16 36	T.	+31 48	E.N.E.	−54	−2 32	−1 48	+27 58	+28 16	
			T.	+31 40	N.E. by E.	−54	−1 43	−1 48	+28 09		
			O.	+32 31	N.E. by E. ½ E.	−54	−1 53	−1 48	+28 50		
1 P.M.	−35 50	16 35	R.	+33 26	N.E. by E.	−54	−1 43	−1 48	+29 55	+30 15	
			R.	+34 23	N.E. by E.	−54	−1 43	−1 48	+30 52		
			R.	+33 28	N.E. by E.	−54	−1 43	−1 48	+29 57		
2 A.M.	−36 36	16 22	T.	+29 15	N.W. ½ W.	−53	+1 41	−1 48	+29 08	+29 49	
			T.	+32 49	S.E. by E.	−53	−2 30	−1 48	+28 31		
2 P.M.	−35 17	16 29	R.	+35 03	E. by S. ½ S.	−53	−2 34	−1 48	+30 41	+30 44	
			R.	+35 20	E. by S. ½ S.	−53	−2 34	−1 48	+30 58		
			R.	+34 54	E. by S. ¼ S.	−53	−2 34	−1 48	+30 32		
3 A.M.	−35 00	17 00	T.	+34 02	E. by S. ½ S.	−53	−2 34	−1 48	+29 40	+30 32	
3 P.M.	−35 03	17 13	T.	+34 20	E. by S.	−53	−2 33	−1 48	+29 59		
			T.	+34 33	E. by S.	−53	−2 33	−1 48	+30 12		
			T.	+35 18	E. by S.	−53	−2 33	−1 48	+30 57		
			T.	+35 22	E. by S.	−53	−2 33	−1 48	+31 01		

Observations of the Declination made on board Her Majesty's Ship 'Terror' in 1842 and 1843, between the Falkland Islands and Cape Horn, and between Cape Horn and the Cape of Good Hope.

The Observers are distinguished in the column of initials as follow:—"C." Captain Crozier; "P." Lieut. Phillips; "Cr." Mr. Cotter, Master; East Declination and South Latitude are characterized by the – sign.

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1842.										
Sept. 12.	–54° 16′	305° 05′	Cr.	–16° 17′	s.e.	–54°	–2° 25′	+1° 13′	–17° 29′	–17° 29′
13.	–54 10	305 35	C.	–18 13	w.	–54	+2 47	–0 40	–16 06	–16 02
			C.	–18 05	w. by s.	–54	+2 47	–0 40	–15 58	
14.	–53 54	304 25	C.	–16 49	s. by w.	–54	+0 15	–0 40	–17 14	–19 55
			Cr.	–22 05	s. by w.	–54	+0 15	–0 40	–22 30	
			Cr.	–19 35	s. by w.	–54	+0 15	–0 40	–20 00	
17.	–55 07	300 19	C.	–23 12	s.w.	–55	+2 05	–0 40	–21 47	–21 43
			C.	–23 30	s.w. by w.	–55	+2 30	–0 40	–21 40	
18.	–55 40	297 00	C.	–25 04	s.w. by s.	–56	+1 37	–0 40	–24 07	–23 58
			C.	–26 15	s.w. ½ w.	–56	+2 22	–0 40	–24 33	
	–55 42	296 22	C.	–24 56	s.w. ½ w.	–56	+2 22	–0 40	–23 14	
Nov. 7.	–56 07	292 53	C.	–20 41	n.e. by e.	–58	–2 14	–0 40	–23 35	–22 14
			C.	–21 46	n.e. by e.	–58	–2 14	–0 40	–24 40	
			C.	–19 18	n.e. by e. ½ e.	–58	–2 25	–0 40	–22 23	
			C.	–15 12	n.e. by e. ½ e.	–58	–2 25	–0 40	–18 17	
8.	–55 42	295 20	C.	–20 10	n.e. by e.	–57	–2 07	–0 40	–22 57	–24 50
			C.	–21 39	n.e. by e.	–57	–2 07	–0 40	–24 26	
			C.	–21 31	n.e. by e.	–57	–2 07	–0 40	–24 18	
			C.	–22 48	n.e. by e.	–57	–2 07	–0 40	–25 35	
			C.	–22 02	n.e. by e.	–57	–2 07	–0 40	–24 49	
			Cr.	–24 10	n.e. by e.	–57	–2 07	–0 40	–26 57	
10.	–55 29	299 03	C.	–25 24	n.w. ½ n.	–56	+1 50	–0 40	–24 14	–24 06
			C.	–23 48	n.w. ¼ n.	–56	+1 57	–0 40	–22 31	
			C.	–21 57	n.	–56	+0 16	–0 40	–22 21	
			C.	–25 17	n.n.w.	–56	+1 12	–0 40	–24 45	
			C.	–23 17	w.	–56	+3 05	–0 40	–20 52	
			C.	–24 17	s.s.w.	–56	+1 00	–0 40	–23 57	
			C.	–26 58	w. by s.	–56	+3 05	0 40	–24 33	
			C.	–28 22	s.w. by w.	–56	+2 36	–0 40	–26 26	
			C.	–24 52	s.s.w.	–56	+1 00	–0 40	–24 32	
			C.	–24 42	w.	–56	+3 05	–0 40	–22 17	
			Cr.	–30 01	s.w.	–56	+2 08	–0 40	–28 33	
11.	–54 43	299 44	C.	–22 09	n.	–55	+0 15	–0 40	–22 34	–22 04
			C.	–22 08	n.w. by n.	–55	+1 34	–0 40	–21 14	
	–54 16	300 05	C.	–24 13	n.	–55	+0 13	–0 40	–24 40	
			C	–22 31	n.	–55	+0 13	–0 40	–22 58	
	–54 38	299 51	Cr.	–19 46	n.w. by n.	–55	+1 34	–0 40	–18 52	
12.	–52 54	301 05	C.	–23 25	n. by w. ½ w.	–53	+0 52	–0 40	–23 13	–22 32
			C.	–22 03	n. by w. ½ w.	–53	+0 52	–0 40	–21 51	
	–52 23	301 30	C.	–21 14	n. by e.	–53	–0 08	–0 40	–22 02	–21 00
			C.	–21 14	n. by e.	–53	–0 08	–0 40	–22 02	
			C.	–21 46	n. by e.	–53	–0 08	–0 40	–22 34	
			C.	–19 38	n. by e.	–53	–0 08	–0 40	–20 26	
			C.	–20 29	n.n.e.	–53	–0 31	–0 40	–21 40	
			C.	–18 26	n. by e. ½ e.	–53	–0 19	–0 40	–19 25	
			C.	–18 27	n. by e ½ e.	–53	–0 19	–0 40	–19 26	
			C.	–19 23	n.e. by n.	–53	–0 57	–0 40	–21 00	
			C.	–19 27	n.n.e.	–53	–0 31	–0 40	–20 38	
	–52 59	301 00	Cr.	–21 10	n.n.w.	–53	+1 03	–0 40	–20 47	
Dec. 18.	–52 46	303 12	C.	–18 59	s.s.e. ½ e.	–53	–1 49	+1 13	–19 35	–19 41
			C.	–19 25	s.e. by s.	–53	–2 02	+1 13	–20 14	
			Cr.	–19 27	e. by n.	–53	–2 19	+1 13	–20 33	
			Cr.	–17 59	s.s.e.	–53	–1 35	+1 13	–18 21	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1842. Dec. 19.	−53° 50′	303° 49′	C.	−21° 11′	S. by E.	−54°	−1° 03′	+1° 13′	−21° 01′	−20° 22′
			C.	−19 18	S.S.E.	−54	−1 38	+1 13	−19 43	
20.	−55 45	305 17	C.	−17 30	S.S.E. ¾ E.	−55	−2 03	+1 13	−18 20	−20 12
			C.	−18 20	S.E. by S.	−55	−2 10	+1 13	−19 17	
			C.	−19 50	S.E. by S.	−55	−2 10	+1 13	−20 47	
			C.	−20 29	S.E. by S.	−55	−2 10	+1 13	−21 26	
			Cr.	−20 34	S.S.E.	−55	−1 41	+1 13	−21 02	
			Cr.	−19 24	S.E. by S.	−55	−2 10	+1 13	−20 21	
21.	−56 34	306 39	C.	−19 10	S.S.E.	−56	−1 44	−0 40	−21 34	−21 09
	−57 15	306 44	C.	−20 07	S. by E.	−56	−1 05	−0 40	−21 52	
			C.	−18 34	S. by E.	−56	−1 05	−0 40	−20 30	
	−56 34	306 39	Cr.	−20 07	S.S.E.	−56	−1 44	+1 13	−20 38	
22.	−58 25	308 00	C.	−20 42	S. by E. ½ E.	−57	−1 28	−0 40	−22 50	−20 06
			C.	−18 44	S. ½ E.	−57	−0 45	−0 40	−20 09	
			C.	−16 17	S.S.E. ½ E.	−57	−2 03	−0 40	−19 02	
			C.	−16 22	S. by E.	−57	−1 06	−0 40	−18 08	
			C.	−15 52	S. by E.	−57	−1 06	−0 40	−17 38	
			C.	−18 41	S.S.E.	−57	−1 47	−0 40	−21 08	
			C.	−19 23	S.S.E.	−57	−1 47	−0 40	−21 50	
23.	−59 28	308 20	C.	−20 05	S.	−58	−0 24	−0 40	−21 09	−21 29
			Cr.	−20 38	S.	−58	−0 24	−0 40	−21 42	
			Cr.	−21 14	S. by W.	−58	+0 19	−0 40	−21 35	
24.	−61 30	307 40	C.	−19 37	S.S.W.	−60	+1 12	−0 40	−19 05	−20 22
			C.	−22 12	S.S.W.	−60	+1 12	−0 40	−21 40	
26.	−62 31	308 05	Cr.	−23 02	N. by W.	−60	+0 50	−0 40	−22 52	−23 50
			Cr.	−26 01	S.W. by S.	−60	+1 53	−0 40	−24 48	
27.	−62 22	308 00	C.	−30 38	W. by S. ½ S.	−60	+3 30	−0 40	−27 48	−22 43
			C.	−24 32	S.W. by W.	−60	+3 04	−0 40	−22 08	
			C.	−24 22	W.S.W.	−60	+3 23	−0 40	−21 39	
			S.	−21 08	S.W. by W.	−60	+3 04	−0 40	−18 44	
	−62 18	308 24	Cr.	−25 10	S.W.	−60	+2 32	−0 40	−23 18	
28.	−62 30	306 30	C.	−29 23	S.W.	−61	+2 38	−0 40	−27 25	−21 41
	−62 41	306 09	C.	−24 54	S.W. ¼ W.	−61	+2 46	−0 40	−22 48	
			C.	−24 42	S.W. ¼ W.	−61	+2 46	+1 13	−20 43	
			C.	−25 07	S.W. ½ W.	−61	+2 54	−0 40	−22 53	
			C.	−24 31	S.W. ½ W.	−61	+2 54	−0 40	−22 17	
			C.	−24 37	S.W. ½ W.	−61	+2 54	+1 13	−20 30	
			C.	−25 40	S.W. ¼ W.	−61	+2 46	+1 13	−21 41	
			C.	−24 49	S.W.	−61	+2 38	+1 13	−20 58	
			C.	−25 24	S.W.	−61	+2 38	−0 40	−23 26	
			C.	−25 41	S.W. ¼ W.	−61	+2 46	+1 13	−21 42	
			C.	−24 38	S.W. ¼ W.	−61	+2 46	+1 13	−20 39	
			C.	−24 10	S.W. ¼ W.	−61	+2 46	+1 13	−20 11	
			C.	−23 58	S.W. by S.	−61	+1 58	+1 13	−20 47	
			S.	−26 06	S.W. by S.	−61	+1 58	+1 13	−22 55	
			S.	−25 48	S.W. ½ W.	−61	+2 54	+1 13	−21 41	
			S.	−22 08	S.W. ½ W.	−61	+2 54	+1 13	−18 01	
			S.	−21 42	S.W. ½ W.	−61	+2 54	+1 13	−17 35	
			S.	−24 38	S.W. ¼ S.	−61	+2 28	+1 13	−20 57	
			Cr.	−25 30	S.W.	−61	+2 38	+1 13	−21 39	
			Cr.	−25 29	S.W.	−61	+2 38	−0 40	−23 31	
			Cr.	−24 38	S.W.	−61	+2 38	+1 13	−20 47	
			Cr.	−25 50	S.W.	−61	+2 38	−0 40	−23 52	
30.	−63 40	304 45	C.	−24 08	S.S.W. ½ W.	−62	+1 40	+1 13	−21 15	−21 15
31.	−63 39	304 40	C.	−22 46	S.	−62	−0 24	+1 13	−21 57	−23 04
			C.	−24 20	S.	−62	−0 24	+1 13	−23 31	
	−64 05	304 00	C.	−20 52	E. by S.	−62	−3 53	+1 13	−23 32	
			C.	−20 53	S.E. by E.	−62	−3 36	+1 13	−23 16	
	−63 45	304 40	C.	−23 55	S.	−62	−0 24	+1 13	−23 06	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Jan. 1.	−64° 10′	304° 40′	C.	−25° 16′	N. ½ E.	−63°	−0° 03′	+1° 13′	−24° 06′	−21° 35′
			Cr.	−23 58	W.N.W.	−63	+3 37	+1 13	−19 08	
			Cr.	−25 44	S.W.	−63	+2 50	+1 13	−21 41	
			Cr.	−22 22	N.N.W.	−63	+1 33	+1 13	−19 36	
			Cr.	−28 16	W.N.W.	−63	+3 37	+1 13	−23 26	
2.	−64 25	303 54	C.	−24 12	N.N.W.	−63	+1 33	+1 13	−21 26	−21 30
			C.	−26 11	N.W. ¾ W.	−63	+3 23	+1 13	−21 35	
4.	−64 38	304 20	C.	−21 06	S.E. by S.	−63	−2 46	+1 13	−22 39	−22 50
			C.	−21 23	S.E.	−63	−3 19	+1 13	−23 29	
			C.	−22 05	S. by E.	−63	−1 17	+1 13	−22 09	
			C.	−24 38	N.N.W.	−63	+1 33	+1 13	−21 52	
			C.	−23 19	N.W. ¾ W.	−63	+3 07	+1 13	−18 59	
	−64 29	303 55	C.	−26 22	W. ¼ S.	−63	+4 01	+1 13	−21 08	−22 44
			C.	−22 30	N.N.E.	−63	−1 01	+1 13	−22 18	
	−64 38	304 26	S.	−23 17	S. by E. ½ E.	−63	−1 43	+1 13	−23 47	
			P.	−23 59	S. by E.	−63	−1 17	+1 13	−24 03	
			P.	−21 13	S.S.E.	−63	−2 10	+1 13	−22 10	
			Cr.	−22 03	S.S.E.	−63	−2 10	+1 13	−23 00	
			Cr.	−23 05	S. by E.	−63	−1 17	+1 13	−23 09	
	−64 29	303 55	Cr.	−27 27	W.	−63	+4 01	+1 13	−22 13	
5.	−64 18	304 04	C.	−25 37	W. by N.	−63	+3 52	+1 13	−20 32	−22 11
	−64 10	303 48	C.	−28 35	W. by N.	−63	+3 52	+1 13	−23 30	
			C.	−28 08	S.S.W. ½ W.	−63	+1 45	+1 13	−25 10	
			C.	−26 01	S.S.W. ½ W.	−63	+1 45	+1 13	−23 03	
			C.	−20 12	E. by N. ½ N.	−63	−3 27	+1 13	−22 26	
			S.	−26 21	W. by N. ½ N.	−63	+3 44	+1 13	−21 24	
			S.	−26 20	W. by N.	−63	+3 55	+1 13	−21 12	
			Cr.	−25 11	W.N.W.	−63	+3 37	+1 13	−20 21	
			Cr.	−26 53	W.N.W.	−63	+3 37	+1 13	−22 03	
6.	−64 12	303 04	C.	−24 03	S. by E.	−63	−1 17	+1 13	−24 07	−23 33
			C.	−27 30	S.W. by W.	−63	+3 25	+1 13	−22 52	
			C.	−20 55	E. by S. ¾ S.	−62	−3 57	+1 13	−23 39	
7.	−64 28	303 20	C.	−23 48	S.S.E.	−63	−2 10	+1 13	−24 45	−24 23
			C.	−28 04	W. ½ N.	−63	+3 57	+1 13	−22 54	
			S.	−24 13	S. by E. ½ E.	−63	−1 43	+1 13	−24 43	
			Cr.	−24 13	S.S.E.	−63	−2 10	+1 13	−25 10	
8.	−64 36	303 10	C.	−25 15	S. by W.	−63	+0 29	+1 13	−23 33	−22 50
			C.	−24 51	N. by W.	−63	+0 55	+1 13	−22 43	
			S.	−25 46	S. by W.	−63	+0 29	+1 13	−24 04	
			P.	−25 19	S.S.W.	−63	+1 22	+1 13	−22 44	
	−64 38	303 38	Cr.	−23 51	N.N.W.	−63	+1 33	+1 13	−21 05	
9.	−64 42	303 20	C.	−21 10	E.S.E.	−63	−3 57	+1 13	−23 44	−24 08
			P.	−21 49	E.S.E.	−63	−3 57	+1 13	−24 33	
	−64 41	302 52	C.	−23 40	Observed on ice.	......	....	....	−23 52	−23 52
			C.	−24 04						
			C.	−23 53						
10.	−64 38	302 40	S.	−28 00	S.W. by W.	−63	+3 25	−0 40	−25 15	−24 37
			P.	−26 44	S.W. by W.	−63	+3 25	−0 40	−23 59	
			Cr.	−23 14	Observed on ice.	......	....	......	−24 07	−24 07
			Cr.	−25 00						
12.	−64 40	302 07	C.	−29 57	W.	−63	+4 01	+1 13	−24 43	−24 43
13.	−64 42	302 42	C.	−22 15	S.E.	−63	−3 19	+1 13	−24 21	−25 59
			C.	−26 15	S. by E.	−63	−1 17	+1 13	−26 19	
			S.	−26 22	W. by N. ½ N.	−63	−3 46	+1 13	−28 55	
			P.	−24 08	S. by E. ½ E.	−63	−1 43	+1 13	−24 38	
			Cr.	−24 44	S.S.E.	−63	−2 10	+1 13	−25 41	
14.	−64 35	302 45	S.	−27 13	W. ½ S.	−63	+4 01	+1 13	−22 03	−23 34
			P.	−27 29	W. ½ N.	−63	+3 57	+1 13	−22 19	
			Cr.	−24 27	S.E.	−63	−3 19	+1 13	−26 33	
15.	−64 30	303 04	C.	−22 23	S.S.E.	−63	−2 10	+1 13	−23 20	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Jan. 18.	−64° 02′	305° 20′	C.	−23° 02′	S. by E.	−63°	−1° 15′	+1° 13′	−23° 04′	−22° 42′
	−64 04	305 00	C.	−25 44	S.S.W. ½ W.	−63	+1 45	+1 13	−22 46	
			C.	−22 18	N.E. by N.	−63	−1 40	+1 13	−22 45	
			C.	−25 59	S.W. by S.	−63	+2 08	+1 13	−22 38	
			C.	−19 34	E. by S. ½ S.	−63	−3 57	+1 13	−22 18	
	−64 02	305 20	S.	−21 43	N.E. ½ N.	−63	−1 58	+1 13	−22 28	−21 49
	−64 04	305 00	S.	−19 16	E.S.E.	−63	−3 57	+1 13	−22 00	
	−64 02	305 20	P.	−20 33	N.E. by N.	−63	−1 40	+1 13	−21 00	
19.	−64 20	306 00	C.	−19 53	S.E. by E.	−63	−3 49	+1 13	−22 29	−21 32
			C.	−25 57	W. by N.	−63	+3 52	+1 13	−20 52	
			S.	−20 18	S.E. by E.	−63	−3 43	+1 13	−22 48	
			S.	−25 26	W.N.W.	−63	+3 37	+1 13	−20 36	
			S.	−26 06	W.	−63	+4 00	+1 13	−20 53	
20.	−64 16	304 42	S.	−20 47	E.	−63	−3 39	+1 13	−23 13	−22 04
			S.	−24 46	W.	−63	+4 00	+1 13	−19 33	
			P.	−28 25	W.S.W.	−63	+3 47	+1 13	−23 25	
21.	−64 20	304 42	S.	−18 58	S.E.	−63	−3 23	+1 13	−21 08	−22 16
22.	−64 09	304 10	C.	−20 15	E. ½ S.	−63	+2 50	+1 13	−22 52	
			C.	−25 36	N.W. ¼ N.	−63	+2 37	+1 13	−21 44	
			S.	−20 24	E. ¾ N.	−63	−3 39	+1 13	−22 50	
			S.	−21 22	E.N.E.	−63	−3 15	+1 13	−23 24	
			P.	−26 52	W. ½ S.	−63	+4 00	+1 13	−21 39	
23.	−64 20	304 00	C.	−27 17	W. by N. ¾ N.	−63	+3 49	+1 13	−22 15	−22 32
			C.	−21 54	E. ¼ N.	−63	−3 39	+1 13	−24 20	
			S.	−25 54	N.W. by W.	−63	+3 25	+1 13	−21 16	
			S.	−26 17	N.W.	−63	+2 46	+1 13	−22 18	
26.	−64 04	304 10	C.	−28 20	W. ½ S.	−63	+4 00	+1 13	−23 07	−22 42
			C.	−22 24	S.E.	−63	−3 23	+1 13	−24 34	
			S.	−25 20	W.N.W.	−63	+3 37	+1 13	−20 30	
			S.	−22 19	S.E.	−63	−3 23	+1 13	−24 29	
			S.	−21 28	S.E. ½ E.	−63	−3 31	+1 13	−23 46	
			P.	−26 50	W. by N.	−63	+3 55	+1 13	−21 42	
28.	−64 02	304 15	P.	−18 22	E. ½ N.	−63	−3 39	+1 13	−20 48	
29.	−64 05	303 55	C.	−21 26	S.E.	−63	−3 23	+1 13	−23 36	−22 28
			C.	−19 49	E. by S.	−63	−3 58	+1 13	−22 34	
			C.	−27 30	S.W. ½ W.	−63	+3 08	+1 13	−23 09	
			C.	−24 32	N. by W. ¼ W.	−63	+1 04	+1 13	−22 15	
			S.	−24 57	W.N.W.	−63	+3 37	+1 13	−20 07	
			S.	−20 55	S.E.	−63	−3 23	+1 13	−23 05	
30.	−64 09	303 57	P.	−25 28	N.W.	−63	+2 46	+1 13	−21 29	−22 13
			P.	−24 47	N.W. ½ N.	−63	+2 28	+1 13	−21 06	
			Cr.	−21 22	E. ½ N.	−63	−3 40	+1 13	−23 49	
			Cr.	−25 20	N.W.	−63	+2 46	+1 13	−21 21	
			Cr.	−20 07	E.S.E.	−63	−3 57	+1 13	−22 51	
			Cr.	−25 28	N.N.W.	−63	+1 33	+1 13	−22 42	
			Cr.	−19 50	E. by N.	−63	−3 39	+1 13	−22 16	
31.	−64 00	304 22	S.	−22 40	N.E. by N.	−63	−1 40	+1 13	−23 07	−23 02
			P.	−23 47	N.E. ½ N.	−63	−1 58	+1 13	−24 32	
			Cr.	−22 54	N. by E.	−63	−0 23	+1 13	−22 04	
			Cr.	−21 56	N.E. by N.	−63	−1 40	+1 13	−22 23	
			Cr.	−22 36	N.E. by N.	−63	−1 40	+1 13	−23 03	
Feb. 1.	−63 56	305 22	S.	−25 19	N.W.	−63	+2 46	+1 13	−21 20	−21 10
			P.	−24 41	W.	−63	+4 00	+1 13	−19 28	
			Cr.	−23 49	N.	−63	+0 15	+1 13	−22 21	
			Cr.	−26 12	S.W. by W.	−63	+3 25	+1 13	−21 34	
			Cr.	−24 33	N.W. by N.	−63	+2 11	+1 13	−21 09	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Feb. 3.	−64° 25′	305° 30′	S.	−22° 05′	S.S.E.	−62°	−2° 08′	+1° 13′	−24° 00′	−22° 17′
			P.	−20 59	N.N.E.	−62	−1 01	+1 13	−20 47	
			P.	−21 00	S.E. by S.	−62	−2 45	+1 13	−22 32	
			Cr.	−22 02	N.N.E.	−62	−1 01	+1 13	−21 50	
4.	−64 16	304 47	Cr.	−25 21	S. by W.	−62	+0 29	+1 13	−23 39	−23 39
9.	−64 10	309 30	C.	−17 24	E.S.E.	−62	−3 57	+1 13	−20 08	−20 05
			C.	−16 11	E. by S. ½ S.	−62	−3 59	+1 13	−18 57	
			S.	−17 55	S.E. ½ S.	−62	−3 00	+1 13	−19 42	
			P.	−17 13	S.E.	−62	−3 19	+1 13	−19 19	
			P.	−17 08	S.E. ¼ S.	−62	−3 11	+1 13	−19 06	
			Cr.	−17 58	S.E. by E.	−62	−3 43	+1 13	−20 28	
			Cr.	−19 48	E.S.E.	−62	−3 57	+1 13	−22 32	
			Cr.	−17 46	E.S.E.	−62	−3 57	+1 13	−20 30	
			Cr.	−16 00	E.S.E.	−62	−3 57	+1 13	−18 44	
			Cr.	−18 42	E.S.E.	−62	−3 57	+1 13	−21 26	
12.	−64 36	315 40	C.	−14 10	N.E. by E.	−61	−2 34	+1 13	−15 31	−16 04
			C.	−14 42	N.E. by E. ½ E.	−61	−2 47	+1 13	−16 16	
			C.	−13 43	E. by N.	−61	−3 23	+1 13	−15 53	
			C.	−14 18	N.E. ½ N.	−61	−1 48	+1 13	−14 53	
			S.	−14 24	E.N.E.	−61	−3 00	+1 13	−16 11	
	−64 50	316 40	P.	−16 36	S.S.E.	−61	−2 03	+1 13	−17 26	
			P.	−15 28	S. by E. ½ E.	−61	−1 41	+1 13	−15 56	
	−64 41	315 55	Cr.	−12 56	N.E. by E.	−61	−2 34	+1 13	−14 17	
			Cr.	−16 46	E.N.E.	−61	−3 00	+1 13	−18 33	
13.	−64 50	316 40	C.	−15 14	S.E. ½ S.	−61	−2 53	+1 13	−16 54	−15 28
			C.	−14 41	S.E. ½ E.	−61	−3 18	+1 13	−16 46	
			S.	−13 32	S. by E. ½ E.	−61	−1 37	+1 13	−13 56	
			Cr.	−14 36	N. by E.	−61	−0 19	+1 13	−13 42	
			Cr.	−13 50	S. by E.	−61	−1 13	+1 13	−13 50	
			Cr.	−13 02	S.S.E.	−61	−2 03	+1 13	−13 52	
			Cr.	−15 08	S.S.E.	−61	−2 03	+1 13	−15 58	
			Cr.	−14 20	E.S.E.	−61	−3 42	+1 13	−16 49	
			Cr.	−15 25	S.E. by S.	−61	−2 36	+1 13	−16 48	
			Cr.	−13 39	E.S.E.	−61	−3 42	+1 13	−16 08	
14.	−65 04	318 20	C.	−12 47	E.	−61	−3 14	+1 13	−14 48	−14 25
			C.	−12 47	E. by N.	−61	−3 23	+1 13	−14 57	
			S.	−13 00	E.	−61	−3 14	+1 13	−14 48	
			S.	−13 18	E. by N.	−61	−3 23	+1 13	−15 28	
			P.	−13 14	E. ½ N.	−61	−3 18	+1 13	−15 19	
			P.	−10 52	E. ½ N.	−61	−3 18	+1 13	−12 57	
	−65 04	318 38	Cr.	−10 10	E.S.E.	−61	−3 42	+1 13	−12 39	
			Cr.	−11 52	E. by S.	−61	−3 45	+1 13	−14 24	
16.	−64 00	321 50	C.	− 7 06	E.	−60	−3 04	+1 13	− 8 57	−10 11
			C.	− 8 24	N.E. ¼ N.	−60	−1 53	+1 13	− 9 04	
	−63 56	321 36	S.	−10 16	N.E. by E.	−60	−2 28	+1 13	−11 31	
			S.	− 8 38	N.E.	−60	−1 59	+1 13	− 9 24	
			Cr.	−10 32	N.E. by E.	−60	−2 28	+1 13	−11 47	
			Cr.	− 9 18	N.E. by E.	−60	−2 28	+1 13	−10 33	
			Cr.	−12 10	N.	−60	+0 16	+1 13	−10 41	
18.	−62 38	328 00	C.	− 6 21	E. by S.	−59	−3 29	+1 13	− 8 37	− 7 37
			C.	− 5 53	E.	−59	−2 58	+1 13	− 7 38	
			C.	− 5 44	E. ¾ N.	−59	−3 05	+1 13	− 7 36	
			S.	− 5 13	E. ½ S.	−59	−3 13	+1 13	− 7 13	
			S.	− 5 21	E.	−59	−2 58	+1 13	− 7 06	
			Cr.	− 6 26	E. ½ S.	−59	−3 13	+1 13	− 8 26	
			Cr.	− 3 57	E. ½ N.	−59	−3 02	+1 13	− 5 46	
			Cr.	− 6 47	E.	−59	−2 58	+1 13	− 8 32	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Feb. 19	−62° 16′	330° 30′	C.	− 4° 30′	E. ½ S.	−59°	−3° 13′	+1° 13′	− 6° 30′	− 6° 30′
			S.	− 5 30	E. by N.	−59	−3 07	+1 13	− 7 24	
			Cr.	− 4 04	E.N.E.	−59	−2 44	+1 13	− 5 35	
20	−62 02	333 40	C.	− 3 42	N. by E.	−58	−0 13	+1 13	− 2 42	− 2 50
			C.	− 3 25	N. by E. ½ E.	−58	−0 30	+1 13	− 2 42	
			C.	− 7 41	W. by N.	−58	+3 15	+1 13	− 3 13	
			C.	− 1 48	N.E. ¾ E.	−58	−2 07	+1 13	− 2 42	
	−61 58	333 44	C.	− 3 59	N. ¾ E.	−58	−0 06	+1 13	− 2 52	− 2 35
			C.	− 3 18	N. ¼ E.	−58	+0 10	+1 13	− 2 05	
			C.	− 2 48	S. ½ E.	−58	−0 45	+1 13	− 2 20	
			C.	− 3 56	S. ¾ W.	−58	+0 08	+1 13	− 2 35	
	−62 02	333 40	S.	− 1 06	E.S.E.	−58	−3 19	+1 13	− 3 12	
			S.	− 2 55	N. by E.	−58	−0 13	+1 13	− 1 57	
			S.	− 8 33	W.	−58	+3 21	+1 13	− 4 00	
			S.	− 2 50	N.E. by E. ½ E.	−58	−2 25	+1 13	− 4 02	
	−61 58	333 48	S.	− 2 44	S. ¾ W.	−58	+0 08	+1 13	− 1 23	
			Cr.	− 3 04	N. by E.	−58	−0 13	+1 13	− 2 04	
			Cr.	− 3 19	N.	−58	+0 16	+1 13	− 1 50	
21	−61 30	335 20	C.	+ 1 20	E. by S.	−58	−3 21	+1 13	− 0 48	− 0 44
	−61 36	336 00	C.	+ 1 41	E. ½ S.	−58	−3 09	+1 13	− 0 15	
			C.	+ 0 52	E. ½ N.	−58	−2 57	+1 13	− 0 52	
	−61 30	335 20	S.	+ 0 50	E. by N.	−58	−2 59	+1 13	− 0 56	
			P.	+ 0 49	E. by N.	−58	−2 59	+1 13	− 0 57	
			Cr.	+ 1 29	E.S.E.	−58	−3 19	+1 13	− 0 37	
24	−62 20	344 00	C.	+ 2 10	S. ½ E.	−59	−0 46	+1 13	+ 2 37	+ 3 29
			C.	+ 2 35	S.	−59	−0 24	+1 13	+ 3 24	
			C.	+ 2 28	S. ½ E.	−59	−0 47	+1 13	+ 2 54	
			S.	+ 2 10	S. by E.	−59	−1 09	+1 13	+ 2 14	
			S.	+ 4 50	S. ¼ E.	−59	−0 35	+1 13	+ 5 28	
			S.	+ 3 42	S. by E.	−59	−1 09	+1 13	+ 3 46	
			P.	+ 3 51	S.	−59	−0 24	+1 13	+ 4 40	
			P.	+ 2 32	S.	−59	−0 24	+1 13	+ 3 21	
			Cr.	+ 3 14	S.	−59	−0 24	+1 13	+ 4 03	
	−62 14	343 37	Cr.	+ 2 26	S. by E.	−59	−1 09	+1 13	+ 2 30	
			Cr.	+ 2 54	S. by E.	−59	−1 09	+1 13	+ 2 58	
			Cr.	+ 3 25	S. ½ E.	−59	−0 46	+1 13	+ 3 52	
25	−64 04	345 16	S.	+ 3 49	S. by E.	−60	−1 11	+1 13	+ 3 51	+ 4 17
		345 04	Cr.	+ 6 07	S. by E.	−60	−1 11	+1 13	+ 6 09	
			Cr.	+ 5 19	S.S.E.	−60	−1 59	+1 13	+ 4 33	
			Cr.	+ 3 55	S.E. by S.	−60	−2 31	+1 13	+ 2 37	
26	−64 24	347 27	C.	+ 6 39	S.E.	−62	−3 15	+1 13	+ 4 37	+ 4 39
			S.	+ 7 23	S.E. ½ E.	−62	−3 25	+1 13	+ 5 11	
			P.	+ 5 23	S.E. ½ E.	−62	−3 25	+1 13	+ 3 11	
			Cr.	+ 7 59	S.E. by E.	−62	−3 36	+1 13	+ 5 36	
27	−65 00	347 27	C.	+ 8 07	S.E.	−62	−3 15	+1 13	+ 6 05	+ 5 58
			C.	+ 6 56	S.E.	−62	−3 15	+1 13	+ 4 54	
		349 24	S.	+ 7 31	S.E.	−62	−3 15	+1 13	+ 5 29	
			S.	+ 8 23	S.E.	−62	−3 15	+1 13	+ 6 21	
	−65 02	349 42	P.	+ 9 33	S.E.	−62	−3 15	+1 13	+ 7 31	
			Cr.	+ 7 35	S.E.	−62	−3 15	+1 13	+ 5 33	
			Cr.	+ 8 48	S.E.	−62	−3 15	+1 13	+ 6 46	
			Cr.	+ 7 12	S.E.	−62	−3 15	+1 13	+ 5 10	
28	−66 00	351 00	C.	+10 15	S.E. ¾ E.	−63	−3 35	+1 13	+ 7 53	+ 8 22
			C.	+11 17	E.S.E.	−63	−4 00	+1 13	+ 8 33	
			S.	+ 9 54	E. by S. ¼ S.	−63	+3 50	+1 13	+ 7 17	
			S.	+ 4 55	S.W.	−63	+2 50	+1 13	+ 8 58	
			P.	+ 4 29	S.W.	−63	+2 50	+1 13	+ 8 32	
			Cr.	+11 02	S.E.	−63	−3 15	+1 13	+ 9 00	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Mar. 1	−67° 12′	350° 36′	C.	+ 3° 28′	s.w. by w.	−63°	+3° 25′	+1° 13′	+ 8° 06′	+ 7° 08′
			C.	+ 2 47	s.w. by w.	−63	+3 25	+1 13	+ 7 25	
			S.	+ 3 34	s.w. by w.	−63	+3 25	+1 13	+ 8 12	
			Cr.	+ 0 57	s.w. by w.	−63	+3 25	+1 13	+ 5 35	
			Cr.	+ 1 46	s.w.	−63	+2 50	+1 13	+ 5 49	
			Cr.	+ 2 39	w.s.w.	−63	+3 47	+1 13	+ 7 39	
2	−68 08	348 10	C.	+ 0 42	s.w.	−64	+2 56	+1 13	+ 4 51	+ 4 15
			C.	+ 0 42	s.w. ½ s.	−64	+2 34	+1 13	+ 4 29	
			C.	+ 0 27	s.w. ½ w.	−64	+3 14	+1 13	+ 4 54	
			C.	+ 0 55	s.w. ½ w.	−64	+3 14	+1 13	+ 5 22	
			C.	+ 1 43	s.w.	−64	+2 56	+1 13	+ 5 52	
			S.	+ 0 29	s.w. by w.	−64	+3 32	+1 13	+ 5 14	
			S.	+ 1 34	s.w. ½ s.	−64	+2 34	+1 13	+ 5 21	
			S.	− 0 21	s.w. by w.	−64	+3 32	+1 13	+ 4 24	
			P.	− 4 15	s.w. ½ w.	−64	+3 14	+1 13	+ 0 12	
			P.	− 4 05	s.w. ½ w.	−64	+3 14	+1 13	+ 0 22	
			Cr.	+ 1 01	s.w.	−64	+2 56	+1 13	+ 5 10	
			Cr.	+ 1 26	s.w. by s.	−64	+2 13	+1 13	+ 4 52	
			Cr.	− 0 34	s.w. by w.	−64	+3 32	+1 13	+ 4 11	
3	−68 30	346 50	C.	+ 5 16	s.s.e.	−64	−2 14	+1 13	+ 4 15	+ 4 15
			C.	+ 3 32	s. ¼ e.	−64	−0 37	+1 13	+ 4 08	
			S.	+ 4 47	s. by e.	−64	−1 19	+1 13	+ 4 41	
			Cr.	+ 5 07	s.s.e.	−64	−2 14	+1 13	+ 4 06	
			Cr.	+ 5 35	s.s.e.	−64	−2 14	+1 13	+ 4 34	
			Cr.	+ 2 53	s.	−64	−0 24	+1 13	+ 3 42	
4	−69 42	345 20	C.	− 2 10	s.s.w. ½ w.	−65	+1 54	+1 13	+ 0 57	+ 1 53
			C.	− 1 44	s.w.	−65	+3 02	+1 13	+ 2 31	
			C.	− 0 25	s.s.w. ½ w.	−65	+1 54	+1 13	+ 2 42	
			S.	− 0 36	s.s.w. ½ w.	−65	+1 54	+1 13	+ 2 31	
			S.	− 0 25	s.s.w. ½ w.	−65	+1 54	+1 13	+ 2 42	
			Cr.	− 2 02	s.w. by s.	−65	+2 18	+1 13	+ 1 29	
			Cr.	− 3 15	s.w. by s.	−65	+2 18	+1 13	+ 0 16	
5	−70 50	343 32	C.	+ 3 00	s.e. by s.	−66	−3 01	+1 13	+ 1 12	+ 2 23
			C.	+ 4 40	s.e.	−66	−3 38	+1 13	+ 2 15	
			S.	+ 0 32	s.s.w. ½ w.	−66	+1 58	+1 13	+ 3 43	
			S.	+ 1 06	s.s.w. ½ w.	−66	+1 58	+1 13	+ 4 17	
			S.	+ 0 25	s. by w.	−66	+0 35	+1 13	+ 2 13	
			S.	+ 3 27	s.e. by s.	−66	−3 01	+1 13	+ 1 39	
	−70 57	343 34	S.	+ 3 12	s.e. by s.	−66	−3 01	+1 13	+ 1 24	
	−70 44	343 48	P.	− 1 52	s.w. by s.	−66	+2 23	+1 13	+ 1 44	+ 2 21
			Cr.	+ 2 12	s.s.w.	−66	+1 33	+1 13	+ 4 58	
			Cr.	+ 3 33	s.e.	−66	−3 37	+1 13	+ 1 09	
			C.	+ 3 57	s.e.	−66	−3 37	+1 13	+ 1 33	
8	−70 24	341 56	S.	+ 0 53	e. by s.	−65	−4 17	+1 13	− 2 11	− 1 59
			Cr.	+ 1 06	e. by s. ½ s.	−65	−4 15	+1 13	− 1 56	
			Cr.	+ 1 11	e. by s. ½ s.	−65	−4 15	+1 13	− 1 51	
11	−66 10	346 40	C.	+ 5 41	n. by e. ½ e.	−62	−0 39	+1 13	+ 6 15	+ 5 35
			S.	+ 4 55	n. by e. ¼ e.	−62	−0 30	+1 13	+ 5 38	
			Cr.	+ 4 10	n. by e. ¼ e.	−62	−0 30	+1 13	+ 4 53	
12	−64 06	346 15	C.	+ 4 51	n.n.e. ½ e.	−60	−1 08	+1 13	+ 4 56	+ 5 29
			S.	+ 5 27	n.e. by n.	−60	−1 25	+1 13	+ 5 15	
			S.	+ 6 30	n.n.e.	−60	−0 52	+1 13	+ 6 51	
			Cr.	+ 4 30	n. by e. ½ e.	−60	−0 34	+1 13	+ 5 09	
			Cr.	+ 5 25	n. by e. ½ e.	−60	−0 34	+1 13	+ 6 04	
			Cr.	+ 3 38	n.	−60	+0 15	+1 13	+ 5 06	
			Cr.	+ 4 26	n. by e. ½ e.	−60	−0 34	+1 13	+ 5 05	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Mar. 13.	−61° 16′	349° 00′	C.	+ 8° 36′	N.N.E. ½ E.	−59	−1° 04′	+1° 13′	+ 8° 45′	+ 7° 16′
			S.	+ 7 05	N.E. by N.	−59	−1 20	+1 13	+ 6 58	
			S.	+ 7 48	N.E. ¾ N.	−59	−1 28	+1 13	+ 7 33	
			P.	+ 5 55	N.E. by N.	−59	−1 20	+1 13	+ 5 48	
15.	−57 36	352 00	C.	+10 55	N.E. ½ N.	−57	−1 27	+1 13	+10 41	+10 35
			C.	+ 9 52	N.N.E. ½ E.	−57	−0 58	+1 13	+10 07	
	−57 22	351 20	C.	+ 9 37	N.N.E. ½ E.	−57	−0 58	+1 13	+ 9 52	
			C.	+ 9 58	N.E. ½ N.	−57	−1 26	+1 13	+ 9 45	
	−57 36	352 00	S.	+10 46	N.E. by N.	−57	−1 12	+1 13	+10 47	
	−57 22	351 20	S.	+11 47	N.E. by N.	−57	−1 12	+1 13	+11 48	
			P.	+11 12	N.E. by N.	−57	−1 12	+1 13	+11 13	
	−57 37	352 00	Cr.	+10 30	N.E. by N.	−57	−1 12	+1 13	+10 31	
15.	−57 22	351 20	Cr.	+12 06	N.E. by N.	−56	−1 08	+1 13	+12 11	+11 33
16.	−57 16	352 54	C.	+ 9 58	N. by W. ¼ W.	−56	+0 52	+1 13	+12 03	
			C.	+ 9 28	N.N.W.	−56	+1 12	+1 13	+11 53	
			C.	+ 8 03	N.W. by N.	−56	+1 39	+1 13	+10 55	
			C.	+12 07	N.E. by E.	−56	−2 00	+1 13	+11 20	
			C.	+11 34	N.E. by E.	−56	−2 00	+1 13	+10 47	
			S.	+10 31	N. by W.	−56	+0 46	+1 13	+12 30	
			S.	+ 7 33	N.W. by W.	−56	+2 25	+1 13	+11 11	
			P.	+ 9 42	N. by W.	−56	+0 46	+1 13	+11 41	
			P.	+ 9 12	N.N.W.	−56	+1 12	+1 13	+11 37	
			Cr.	+ 7 48	N.W. by W.	−56	+2 25	+1 13	+11 26	
			Cr.	+11 10	E. by N.	−56	−2 43	+1 13	+ 9 40	
			Cr.	+12 12	E.N.E.	−56	−2 22	+1 13	+11 03	
17.	−56 42	353 40	C.	+13 15	N.E. by E.	−56	−2 00	+1 13	+12 28	+11 22
			S.	+11 25	E.N.E.	−56	−2 22	+1 13	+10 16	
18.	−55 58	355 30	C.	+14 32	E.	−56	−2 44	+1 13	+13 01	+12 57
			S.	+14 57	E.	−56	−2 44	+1 13	+13 26	
			Cr.	+14 00	E.	−56	−2 44	+1 13	+12 25	
19.	−54 30	357 50	S.	+15 14	E. by N.	−55	−2 35	+1 13	+13 52	+13 52
20.	−54 06	359 30	C.	+17 05	E.S.E.	−55	−2 58	+1 13	+15 20	+14 49
			C.	+17 31	E.S.E.	−55	−2 58	+1 13	+15 46	
			C.	+17 21	S.E. by E.	−55	−2 47	+1 13	+15 47	
			C.	+18 26	S.E. ½ E.	−55	−2 40	+1 13	+16 59	
			S.	+15 50	S.E. by S.	−55	−2 10	+1 13	+14 53	
	−54 26	0 26	S.	+18 17	E.S.E.	−55	−2 58	+1 13	+16 32	
			Cr.	+13 04	E.S.E.	−55	−2 58	+1 13	+11 19	
			Cr.	+13 40	E.S.E.	−55	−2 58	+1 13	+11 55	
24.	−49 57	9 38	C.	+23 59	N.E.	−56	−1 31	+1 13	+23 41	+24 07
			S.	+24 51	N.E.	−56	−1 31	+1 13	+24 33	
25.	−47 20	10 55	C.	+25 14	N.E.	−55	−1 27	+1 13	+25 00	+24 29
			C.	+24 54	N.E. by N.	−55	−1 04	+1 13	+25 03	
			S.	+24 17	N.E.	−55	−1 27	+1 13	+24 03	
			S.	+24 03	N.E.	−55	−1 27	+1 13	+23 49	
27.	−43 53	13 20	C.	+27 11	E.N.E.	−55	−2 15	+1 13	+26 09	+26 46
	−43 57	13 50	C.	+28 09	E. ¼ N.	−55	−2 39	+1 13	+26 43	
	−43 10	13 20	S.	+27 51	E.N.E.	−55	−2 15	+1 13	+26 49	
			S.	+28 43	E. by N.	−55	−2 35	+1 13	+27 21	
			Cr.	+28 08	E. by N.	−55	−2 35	+1 13	+26 46	
28.	−43 08	14 40	S.	+27 47	N.E.	−55	−1 30	+1 13	+27 30	+27 33
			S.	+27 54	N.E.	−55	−1 30	+1 13	+27 37	
29.	−42 06	14 57	Cr.	+28 02	N.E.	−54	−1 30	+1 13	+27 45	+27 29
	−41 36	15 10	S.	+27 30	N.E.	−54	−1 30	+1 13	+27 13	
30.	−40 22	16 00	C.	+26 36	N.E.	−54	−1 30	+1 13	+26 19	+26 53
			C.	+27 07	N.E.	−54	−1 30	+1 13	+26 50	
			S.	+27 29	N.E.	−54	−1 30	+1 13	+27 12	
			S.	+27 04	N.E.	−54	−1 30	+1 13	+26 47	
			Cr.	+27 35	N.E.	−54	−1 30	+1 13	+27 18	

Observations of Declination, Her Majesty's Ship 'Terror' (continued).

Date.	Position.		Initials.	Declination observed.	Direction of ship's head.	Approximate Inclination.	Corrections.		Declination.	
	Lat.	Long.					Deviation.	Index.		
1843. Mar. 30.	−39° 23′	16° 08′	Cr.	+28° 25′	N.E. by E.	−54°	−1° 45′	+1° 13′	+27° 53′	
31.	−38 26	16 39	S.	+29 08	N.E. by E.	−54	−1 45	+1 13	+28 36	+27° 43′
			S.	+28 36	N.E. ½ E.	−54	−1 34	+1 13	+28 15	
			Cr.	+26 50	N.E. by E.	−54	−1 45	+1 13	+26 18	
April 1.	−36 15	16 31	S.	+29 08	N.E. by E.	−53	−1 45	+1 13	+28 36	+28 43
			Cr.	+28 43	N.E. by E.	−53	−1 45	+1 13	+28 11	
			C.	+29 53	N.E. by E.	−53	−1 45	+1 13	+29 21	
3.	−35 26	16 14	S.	+27 49	N.E. ½ N.	−53	−1 11	+1 13	+27 51	+28 00
			Cr.	+29 42	E.N.E.	−53	−2 06	+1 13	+28 52	
			C.	+27 50	N.E. by E.	−53	−1 45	+1 13	+27 18	

Observations of the INCLINATION made on board Her Majesty's Ship 'Erebus' with Needle R. F. 5, between September 1842 and April 1843 (being a continuation from Contributions No. VI., Philosophical Transactions, 1844, pp. 151 to 168).

Observers Captain Sir JAMES CLARK ROSS and Lieut. ALEXANDER JOHN SMITH, R.N.

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1842. Sept. 8.	Running out of Berkeley Sound.		Direct.	−52° 38′	E. ½ N.	+0 17′	−6′	−52° 34′	
			S.	−52 58					
	−51° 32′	301° 53′	N.	−52 44					
			N.S.	−52 41					
9.	−53 33	302 05	Direct.	−52 26	S.S.W.	−0 54	−6	−53 34	
			S.	−52 19					
			N.	−52 45					
			N.S.	−52 45					
			Direct.	−52 33					
13.	−54 03	305 26	Direct.	−54 38	W.S.W.	−0 10	−6	−54 31	
			S.	−54 08					
			N.	−54 10					
			N.S.	−53 51					
			Direct.	−54 27					
14.	−53 47	304 48	Direct.	−53 11	S. by W.	−0 59	−6	−54 25	
			S.	−53 10					
			N.	−53 39					
			N.S.	−53 21					
			Direct.	−53 18					
15.	−54 43	304 30	Direct.	−54 00	S.E.	−0 33	−6	−54 44	
			N.	−54 24					
			N.S.	−54 03					
			Direct.	−53 54					
16.	−54 41	304 48	Direct.	−54 29	E.	+0 11	−6	−54 24 } −54° 16′	
			Direct.	−54 06	W.S.W.	−0 10	−6	−54 14	
			S.	−53 49					
			N.	−54 03					
			N.S.	−53 47					
			Direct.	−54 03					
17.	−55 08	300 44	Direct.	−55 59	S.W. by W.	−0 28	−6	−56 33	
18.	−55 40	296 52	Direct.	−57 10	S.W. ½ W.	−0 38	−6	−57 33	
			S.	−57 02					
			N.	−57 00					
			N.S.	−57 01					
			wt. 1 gr.	−56 18					
			wt. 2 grs.	−57 06					
			wt. 3 grs.	−56 44					
			wt. 4 grs.	−56 11					
19.	Standing towards St. Martin's Cove, Chanticlear Point, N.W., distant 6 miles.		Direct.	−58 34	W.S.W.	−0 17	−6	−58 57 } −58 52	
			Direct.	−59 11	W.N.W.	+0 25	−6	−59 01	
			S.	−59 51					
			N.	−59 14					
			Direct.	−59 05					
			Direct.	−58 48	W.	+0 11	−6	−58 43	
			Direct.	−59 00	N.E.	+0 49	−6	−58 17	

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1842. Nov. 7.	Running out of		Direct.	−57° 45′	S.E.	−0° 41′	−6′	−58° 37′	
	St. Martin's Cove.		S.	−57 47					
	−56 25	293 07	N.	−57 51					
			N.S.	−57 56					
			Direct.	−57 52					
8.	−55 38	296 00	Direct.	−57 17	N.E. by E.	+0 44	−6	−56 46	
			S.	−57 08					
			N.	−57 45					
			N.S.	−57 29					
			Direct.	−57 21					
9.	−55 58	299 12	Direct.	−57 05	E. ½ N.	+0 18	−6	−56 53	
10.	−55 32	299 08	Direct.	−55 50	S.W. by W.	−0 30	−6	−56 21	
			Direct.	−56 21	W.	+0 11	−6		
11.	−54 24	300 08	Direct.	−56 02	N.	+0 44	−6	−55 06	
			S.	−56 18					
			N.	−56 06					
			N.S.	−56 25					
			wt. 1 gr.	−55 21					
			wt. 2 grs.	−55 26					
			wt. 3 grs.	−55 05					
			wt. 4 grs.	−54 54					
			Direct.	−56 03					
12.	−52 52	301 05	Direct.	−54 38	N.	+0 40	−6	−53 32	
			S.	−54 39					
			N.	−54 42					
			N.S.	−54 27					
			wt. 1 gr.	−53 33					
			wt. 2 grs.	−53 50					
			wt. 3 grs.	−53 27					
			wt. 4 grs.	−53 07					
			Direct.	−54 28					
Dec. 13.	−51 32	301 53	Direct.	−52 12	Observed on shore.	……	−6	−52 49	Upper Dip House.
	(on shore)		S.	−53 20					
	Port Louis,		N.	−52 18					
	Falkland Islands.		N.S.	−52 26					
			wt. 1 gr.	−52 43					
			wt. 2 grs.	−52 46					
			wt. 3 grs.	−53 05					
			wt. 4 grs.	−52 55					
			wt. 5 grs.	−53 16					
			Direct.	−52 11					
17.	Running out of		Direct.	−52 29	S.E. by S.	−0 40	−6	−52 42	
	Port Louis,		S.	−53 15					
	Berkeley Sound.		N.	−52 40					
	−51 32	301 53	N.S.	−52 49					
			wt. 1 gr.	−51 27					
			wt. 2 grs.	−50 47					
			wt. 3 grs.	−51 22					
			wt. 4 grs.	−51 11					
			wt. 5 grs.	−51 36					
			wt. 6 grs.	−51 49					
18.	−52 50	303 07	Direct.	−52 42	S.E. by S.	−0 40	−6	−53 29	
			S.	−52 30					
			N.	−52 44					
			N.S.	−53 04					
			Direct.	−52 37					

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1842. Dec. 19.	−54° 23′	303° 59′	Direct.	−53° 58′	S.S.E.	−0° 52′	−6′	−54° 43′	
			S.	−53 20					
			N.	−53 40					
			N.S.	−53 25					
			Direct.	−54 06					
20.	−55 51	305 18	Direct.	−54 48	S.E. by S.	−0 45	−6	−55 35	
			S.	−54 57					
			N.	−54 18					
			N.S.	−54 45					
			Direct.	−54 52					
21.	−56 34	306 39	Direct.	−55 12	S.S.E.	−0 58	−6	−56 14	
			S.	−55 13					
			N.	−54 57					
			N.S.	−54 51					
			Direct.	−55 38					
22.	−58 16	308 00	Direct.	−56 13	S. by E. ½ E.	−1 03	−6	−57 21	
			S.	−56 06					
			N.	−56 12					
			N.S.	−56 12					
			Direct.	−56 17					
23.	−59 28	308 20	Direct.	−57 21	S. by W.	−1 10	−6	−58 46	
			S.	−57 14					
			N.	−57 05					
			N.S.	−57 15					
			Direct.	−57 25					
			wt. 1 gr.	−57 35					
			wt. 2 grs.	−58 16					
			wt. 3 grs.	−57 56					
24.	−61 23	307 41	Direct.	−58 30	S. by W.	−1 16	−6	−59 51	
			N.	−58 39					
			N.S.	−58 17					
25.	−62 14	307 55	Direct.	−59 48	S.S.E.	−1 09	−6	−61 03	
26.	−62 31	308 05	Direct.	−61 20	N. by W.	+1 00	−6	−60 34	
			S.	−61 33					
			N.	−61 29					
			N.S.	−61 31					
27.	−62 22	308 00	Direct.	−59 56	S.W.	−0 51	−6	−60 36	
			S.	−59 22					
			N.	−59 26					
			N.S.	−59 48					
			Direct.	−59 14	S.	−1 20	−6		
	−62 18	308 24	Direct.	−60 04	W.S.W.	−0 19	−6	−61 04	
			wt. 1 gr.	−60 21					
			wt. 2 grs.	−60 55					
			wt. 3 grs.	−61 32					
			wt. 4 grs.	−60 15					
			wt. 5 grs.	−60 46					
28.	−62 30	306 30	Direct.	−60 16	S.W.	−0 52	−6	−61 18	
			S.	−60 26					
			N.	−60 13					
			N.S.	−60 33					
			Direct.	−60 13					
29.	−62 36	306 20	Direct.	−60 54	S.	−1 23	−6	−62 23	−61° 45′
			Direct.	−62 33	N.N.E.	+1 06	−6	−61 41	
			S.	−62 47					
			N.	−62 45					
			N.S.	−62 25					
			Direct.	−62 10	N.E. by E.	+0 51	−6	−61 25	

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.		Remarks.
						Ship's attraction.	Index.			
1842. Dec. 30.	−63° 36′	305° 00′	Direct.	−62° 12′	E. by S.	−0° 03′	−6′	−62° 20′	−62° 18′	
			S.	−62 14						
			N.	−61 57						
			N.S.	−62 22						
			Direct.	−62 14	W.	+0 11	−6	−62 09		
31.	−63 39	304 40	Direct.	−61 22	S. by E.	−1 17	−6	−62 45	−62 29	
			S.	−61 40	S.S.E.	−1 11	−6	−62 28		
			N.	−61 21						
			N.S.	−61 29						
			wt. 1 gr.	−60 36						
			wt. 2 grs.	−61 08						
			wt. 3 grs.	−60 52						
			Direct.	−61 55	W. by S.	−0 05	−6	−62 06		
			Direct.	−61 09	S.W. by S.	−1 05	−6	−62 20		
	−63 45	304 40	Direct.	−61 12	S. by W.	−1 19	−6	−61 56		
			wt. 4 grs.	−61 02						
			wt. 5 grs.	−59 52						
			wt. 6 grs.	−60 03						
1843. Jan. 1.	−64 23	304 00	Direct.	−62 23	W. by S.	−0 05	−6	−63 04		
			wt. 1 gr.	−62 34						
			wt. 2 grs.	−63 08						
			wt. 3 grs.	−62 52						
			wt. 4 grs.	−63 06						
			wt. 5 grs.	−63 18						
2.	−64 26	303 52	Direct.	−63 10	Observed on ice.	......	−6	−63 16		
			S.	−63 19						
			N.	−62 59						
			N.S.	−63 11						
			Direct.	−63 09						
3.	−64 12	304 11	Direct.	−63 30	N.E. ½ N.	+1 01	−6	−62 35	−62 48	
4.	−64 32	304 20	Direct.	−63 34	N. by W. ½ W.	+1 07	−6	−62 45		
			S.	−63 55						
			N.	−63 39						
			N.S.	−63 44						
			Direct.	−62 03	S. by E. ½ E.	−1 07	−6	−63 16		
5.	−64 12	304 04	Direct.	−62 57	W. by N.	+0 20	−6	−62 43	−63 01	
			Direct.	−62 35	S.W. ½ W.	−0 47	−6	−63 28		
			Direct.	−62 56	E.	+0 11	−6	−62 51		
7.	−64 34	302 50	Direct.	−63 53	W.N.W.	+0 29	−6	−63 24	−63 36	
			S.	−63 49						
			N.	−63 44						
			N.S.	−63 41						
			Direct.	−62 15	S.S.E.	−1 13	−6	−63 34		
			Direct.	−63 00	S. by E.	−1 19	−6	−64 25		
8.	−64 35	302 13	Direct.	−62 09	S. by E.	−1 19	−6	−63 34	−63 30	
			Direct.	−62 24	S.S.E.	−1 13	−6	−63 43		
			Direct.	−63 06	S.E. by E.	−0 35	−6	−63 47		
			Direct.	−64 00	N. by W. ½ W.	+1 08	−6	−62 58		
9.	−64 44	303 07	Direct.	−63 13	Observed on ice.	....	−6	−63 21		
			S.	−63 50						
			N.	−63 22						
			N.S.	−63 29						
			wt. 1 gr.	−64 04						
			wt. 2 grs.	−64 12						
			wt. 3 grs.	−62 41						
			wt. 4 grs.	−62 12						
			wt. 6 grs.	−62 14						
			Direct.	−63 15						

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.		Remarks.
						Ship's attraction.	Index.			
1843. Jan. 10.	−64° 43′	303° 10′	Direct.	−62° 30′	S. ½ W.	−1° 24′	−6′	−64° 00′	−63° 30′	
			Direct.	−62 22	S.W. by S.	−1 09	−6	−63 37		
11.	−64 42	302 54	Direct.	−63 30	W. ½ N.	+0 16	−6	−63 20		
12.	−64 39	302 04	Direct.	−62 03	S.S.E.	−1 13	−6	−63 22		
			Direct.	−63 40	W.N.W.	+0 30	−6	−63 15		
13.	−64 35	302 37	Direct.	−62 07	S.	−1 27	−6	−63 40		
			Direct.	−63 48	N.W. by W.	+0 42	−6	−63 12		
14.	−64 31	302 34	Direct.	−63 19	W.	+0 11	−6	−63 38		
			S.	−64 41						
			N.	−63 28						
			N.S.	−63 23						
16.	−64 28	303 03	Direct.	−63 53	N.N.W. ½ W.	+1 04	−6	−63 06		
			S.	−64 15						
			N.	−64 06						
			N.S.	−64 04						
	−64 28	303 03	Direct.	−63 11	Observed on ice.	....	−6	−63 43		
			S.	−64 27						
			N.	−63 29						
			N.S.	−63 19						
18.	−63 58	304 46	Direct.	−63 08	E. ½ N.	+0 20	−6	−62 54		
19.	−64 22	305 01	Direct.	−62 55	E.	+0 11	−6	−63 08		
			S.	−63 42						
			N.	−63 21						
			N.S.	−63 09						
			Direct.	−62 59						
20.	−64 18	304 18	Direct.	−62 33	W.S.W.	−0 21	−6	−63 20		
			S.	−63 56						
			N.	−62 36						
			N.S.	−62 35						
			Direct.	−62 43						
21.	−64 19	304 04	Direct.	−63 04	E.	+0 11	−6	−62 59	−63 00	
			Direct.	−62 34	W.S.W.	−0 21	−6	−63 01		
22.	−64 12	303 50	Direct.	−63 10	E.N.E.	+0 47	−6	−62 21	−62 26	
			S.	−61 47						
			N.	−63 33						
			N.S.	−63 36						
			Direct.	−63 33	N.W.	+0 51	−6	−62 48		
23.	−64 24	304 49	Direct.	−63 12	E. by N.	+0 29	−6	−62 49	−62 40	
			Direct.	−63 12	N.W. by W. ½ W.	+0 34	−6	−62 44		
24.	−64 24	304 49	Direct.	−63 26	N.N.E. ½ E.	+1 06	−6	−62 26		
25.	−64 15	304 00	Direct.	−62 22	S.E.	−0 51	−6	−63 19	−62 56	
			Direct.	−62 38	W.	+0 11	−6	−62 33		
26.	−64 04	305 19	Direct.	−62 59	W. by N.	+0 20	−6	−62 45	−62 57	
			Direct.	−62 11	S.E.	−0 52	−6	−63 09		
27.	−64 08	304 09	Direct.	−63 25	N.E.	+0 59	−6	−62 32	−62 42	
			Direct.	−63 28	N. ½ W.	+1 08	−6	−62 26		
			Direct.	−61 37	S.	−1 25	−6	−63 08		
28.	−64 08	304 08	Direct.	−62 55	E.	+0 11	−6	−62 50	−62 38	
			Direct.	−63 13	N.E. by E.	+0 53	−6	−62 26		
29.	−64 05	304 0	Direct.	−62 43	W.	+0 11	−6	−62 41	−62 46	
			S.	−62 52						
			N.	−62 40						
			N.S.	−62 51						
			Direct.	−62 18	S.E. ½ E.	−0 43	−6	−63 07		
30.	−64 09	303 57	Direct.	−63 05	E.	+0 11	−6	−63 00	−63 00	

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.		Remarks.
						Ship's attraction.	Index.			
1843. Jan. 31.	−64° 00′	304° 42′	Direct.	−62° 54′	E.N.E.	+0° 47′	−6′	−62° 13′	−62° 23′	
			Direct.	−62 54	E.	+0 11	−6	−62 49		
			Direct.	−63 05	N.E. by N.	+1 05	−6	−62 06		
Feb. 1.	−63 53	304 51	Direct.	−61 53	S.W. by W.	−0 37	−6	−62 36	−62 28	
			Direct.	−62 47	N.N.W.	+1 03	−6	−61 50		
			Direct.	−61 53	S.E. by S.	−1 00	−6	−62 59		
2.	−64 16	304 38	Direct.	−63 01	E. by N.	+0 28	−6	−62 39	−62 33	
			Direct.	−63 13	N.E. by E.	+0 52	−6	−62 27		
3.	−64 17	305 20	Direct.	−63 06	N.N.E.	+1 06	−6	−62 06	−62 22	
			Direct.	−63 12	N. by E.	+1 06	−6	−62 12		
			Direct.	−61 24	S.	−1 23	−6	−62 47		
4.	−64 16	304 47	Direct.	−63 14	N.E. ½ N.	+1 02	−6	−62 18	−62 45	
			Direct.	−63 16	N.E. by E.	+0 52	−6	−62 30		
			Direct.	−61 48	S.S.W.	−1 17	−6	−63 11		
			Direct.	−61 31	S. ½ W.	−1 23	−6	−63 00		
5.	−63 34	307 00	Direct.	−62 23	N.E.	+0 57	−6	−61 42	−61 34	
			S.	−62 44						
			N.	−62 31						
			N.S.	−62 11	N.E. ½ N.	+0 59	−6	−61 29		
			Direct.	−62 23						
6.	−63 35	307 33	Direct.	−62 21	N. ½ E.	+1 06	−6	−61 37		
			S.	−63 26						
			N.	−62 20						
			N.S.	−62 36						
			Direct.	−62 21						
7.	−63 54	308 00	Direct.	−62 13	N. by E. ½ E.	+1 02	−6	−61 17	−61 50	
			Direct.	−61 12	S.S.E. ½ E.	−1 03	−6	−62 21		
8.	−63 49	309 00	Direct.	−61 49	E. ½ S.	+0 04	−6	−62 06		
			S.	−62 46						
			N.	−61 54						
			N.S.	−62 00						
			Direct.	−61 51						
9.	−64 19	309 36	Direct.	−61 29	E.S.E.	−0 18	−6	−62 33		
			S.	−61 56						
			N.	−61 36						
			N.S.	−61 50						
			wt. 1 gr.	−62 41						
			wt. 2 grs.	−62 32						
			wt. 3 grs.	−62 46						
			wt. 4 grs.	−62 37						
			wt. 5 grs.	−62 37						
			wt. 6 grs.	−61 31						
10.	−64 36	311 53	Direct.	−62 13	N.E. by E.	+0 51	−6	−61 41		
			S.	−62 37						
			N.	−62 35						
			N.S.	−62 36						
			Direct.	−62 11						
11.	−64 37	314 21	Direct.	−61 05	S.E. ½ S.	−0 54	−6	−62 15	−62 07	
			S.	−61 45						
			N.	−61 03						
			N.S.	−61 22						
			Direct.	−61 02						
			Direct.	−62 23	N.N.E. ½ E.	+1 04	−6	−61 25		
12.	−64 39	316 04	Direct.	−62 13	N.E.	+0 57	−6	−61 30		
			S.	−63 04						
			N.	−62 12						
			N.S.	−62 10						
			Direct.	−62 08						

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.		Remarks.
						Ship's attraction.	Index.			
1843. Feb. 13.	−64° 38′	316° 57′	Direct.	−60° 27′	S. by E.	−1° 18′	−6′	−62° 10′	−61° 57′	
			S.	−61 44						
			N.	−60 24						
			N.S.	−60 28						
			Direct.	−62 05	N. by E.	+1 06	−6	−61 05		
14.	−65 06	318 46	Direct.	−62 02	E.N.E.	+0 46	−6	−61 35		
			S.	−62 38						
			N.	−62 31						
			N.S.	−62 11						
			Direct.	−62 01						
15.	−64 40	320 12	S.	−62 54	N.E. by N.	+1 00	−6	−61 08		
			N.	−62 08						
			N.S.	−61 45						
			Direct.	−61 41						
			Direct.	−61 40						
16.	−63 54	321 36	Direct.	−61 05	N.E. by E. ½ E.	+0 46	−6	−60 27		
			S.	−61 57						
			N.	−61 04						
			N.S.	−60 36						
			Direct.	−60 55						
17.	−63 36	324 36	Direct.	−60 14	N. by W.	+0 58	−6	−59 22	−59 43	
			Direct.	−60 05	N. by E.	+0 57	−6	−59 14		
			Direct.	−59 57	N.N.E.	+0 57	−6	−59 25		
			S.	−60 57						
			N.	−60 13						
			N.S.	−60 11						
			wt. 1 gr.	−60 54	E.N.E.	+0 44	−6	−60 05		
			wt. 2 grs.	−60 53						
			wt. 3 grs.	−60 49						
			wt. 4 grs.	−60 47						
			wt. 5 grs.	−60 59						
			wt. 6 grs.	−60 33						
			Direct.	−60 03						
			Direct.	−59 59	N.E.	+0 53	−6	−59 12		
18.	−62 39	328 16	Direct.	−59 32	N.E. by E.	+0 47	−6	−58 18	−58 42	
			S.	−59 42						
			N.	−59 30						
			N.S.	−59 35						
			Direct.	−59 28						
			wt. 2 grs.	−59 40	E.N.E.	+0 44	−6	−59 21		
			wt. 3 grs.	−59 49						
			wt. 4 grs.	−60 30						
19.	−62 20	330 00	Direct.	−59 07	N.E. by E. ½ E.	+0 46	−6	−58 36		
			S.	−59 23						
			N.	−59 18						
			N.S.	−59 16						
20.	−61 59	333 43	Direct.	−58 40	N.E.	+0 50	−6	−58 13		
			S.	−59 32						
			N.	−59 00						
			N.S.	−58 52						
			Direct.	−58 41						
21.	−61 37	336 05	Direct.	−58 07	E. by S.	−0 02	−6	−58 24	−58 18	
			S.	−58 22						
			N.	−58 13						
			N.S.	−58 22						
			Direct.	−58 15	E. by N.	+0 27	−6	−57 54		

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1843. Feb. 22.	−61° 30′	338° 00′	Direct.	−57° 55′	E. by N.	+0° 27′	−6′	−57° 50′	
			S.	−58 30					
			N.	−58 02					
			N.S.	−58 31					
			Direct.	−57 55					
23.	−61 46	341 02	Direct.	−57 43	E.S.E.	−0 14	−6	−58 18	
			S.	−58 30					
			N.	−57 58					
			N.S.	−57 54					
			Direct.	−57 47					
24.	−62 36	344 08	Direct.	−57 27	S.	−1 16	−6	−59 12	
			S.	−58 04					
			N.	−57 40					
			N.S.	−58 14					
			Direct.	−57 45					
25.	−63 58	345 10	Direct.	−59 18	S. by E.	−1 14	−6	−60 42	−60° 42′
			S.	−59 29					
			N.	−59 10					
			N.S.	−59 29					
			Direct.	−59 27	S.S.E.	−1 09	−6	−60 42	
26.	−64 38	348 00	Direct.	−60 26	S.E.	−0 47	−6	−61 21	
			S.	−60 38					
			N.	−60 06					
			N.S.	−60 47					
			Direct.	−60 22					
27.	−65 12	350 05	Direct.	−60 48	S.E.	−0 49	−6	−61 49	
			S.	−61 04					
			N.	−60 47					
			N.S.	−60 59					
			Direct.	−60 50					
28.	−66 08	352 43	Direct.	−62 13	S.E. by S.	−1 02	−6	−63 14	
			S.	−62 25					
			N.	−62 00					
			N.S.	−61 45					
			Direct.	−62 05					
Mar. 1.	−67 06	351 04	Direct.	−62 19	S.W. ½ W.	−0 47	−6	−63 19	
			S.	−62 43					
			N.	−62 31					
			N.S.	−62 22					
			Direct.	−62 13					
2.	−68 14	347 08	Direct.	−62 56	S.W.	−0 58	−6	−64 24	
			S.	−62 53					
			N.	−63 02					
			N.S.	−63 23					
			Direct.	−63 01					
			wt. 1 gr.	−63 21					
			wt. 2 grs.	−64 00					
			wt. 3 grs.	−63 41					
			wt. 4 grs.	−63 47					
3.	−68 32	347 09	Direct.	−62 53	S.S.E.	−1 15	−6	−64 21	
			S.	−62 58					
			N.	−63 03					
			N.S.	−63 10					
			Direct.	−62 54					

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1843. Mar. 4.	−69° 26′	345° 31′	Direct.	−63° 27′	s.w. by s.	−1° 10′	−6′	−64° 48′	
			S.	−63 36					
			N.	−63 30					
			N.S.	−63 35					
			Direct.	−63 25					
5.	−71 10	344 13	Direct.	−65 08	s.e.	−0 53	−6	−66 13	
			S.	−65 16					
			N.	−65 12					
			N.S.	−65 23					
			Direct.	−65 13					
6.	−70 55	343 14	Direct.	−65 48	e. ½ n.	+0 23	−6	−65 31	
8.	−70 28	342 39	Direct.	−65 10	e.s.e.	−0 22	−6	−65 38	
9.	−69 56	344 03	Direct.	−65 10	n.n.e.	+1 12	−6	−64 04	
10.	−68 06	344 40	Direct.	−64 12	n.e. by n.	+1 04	−6	−63 01	
			N.	−63 45					
			S.	−63 47					
			Direct.	−64 12					
11.	−65 56	346 24	Direct.	−62 36	n. by e.	+1 06	−6	−61 47	
			S.	−63 28					
			N.	−62 20					
			N.S.	−62 53					
			Direct.	−62 40					
12.	−64 31	346 01	Direct.	−60 39	n.n.e.	+1 00	−6	−59 50	
			N.	−60 27					
			S.	−61 03					
			Direct.	−60 45					
13.	−61 34	348 37	Direct.	−59 36	n.e. by n.	+0 53	−6	−58 50	
			S.	−60 03					
			N.	−59 32					
			N.S.	−59 24					
			Direct.	−59 30					
14.	−59 34	350 34	Direct.	−57 57	n.e. by n.	+0 50	−6	−57 27	
			S.	−58 58					
			N.	−58 13					
			N.S.	−57 52					
			Direct.	−57 54					
15.	−57 27	352 08	Direct.	−57 02	n.e. by n.	+0 49	−6	−56 37	
			S.	−58 30					
			N.	−57 06					
			N.S.	−56 48					
			Direct.	−57 03					
			wt. 2 grs.	−58 25					
			wt. 3 grs.	−57 41					
			wt. 4 grs.	−56 01					
16.	−57 09	352 45	Direct.	−56 48	n.w. ½ n.	+0 42	−6	−56 28	
			S.	−57 55					
			N.	−57 27					
			N.S.	−56 32					
			Direct.	−56 40					
17.	−56 38	353 57	Direct.	−56 36	n.n.w.	+0 47	−6	−56 06	
			S.	−57 38					
			N.	−56 36					
			N.S.	−56 32					
			Direct.	−56 34					

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.	Remarks.
						Ship's attraction.	Index.		
1843. Mar. 18.	−55° 38′	355° 32′	Direct.	−56° 34′	E.N.E.	+0° 41′	−6′	−56° 45′	
			S.	−58 48					
			N.	−57 45					
			N.S.	−57 07					
			Direct.	−56 28					
19.	−54 31	357 35	Direct.	−55 56	E. by N.	+0 26	−6	−55 36	
20.	−54 07	359 56	Direct.	−55 17	E.S.E.	−0 12	−6	−55 37	
			S.	−55 28					
			N.	−55 29					
			N.S.	−55 49					
			Direct.	−55 17					
			S.	−54 18					
			N.	−55 35					
24.	−50 37	9 03	Direct.	−56 45	N.E.	+0 46	−6	−56 09	
			S.	−56 28					
			N.	−57 02					
			N.S.	−57 03					
25.	−47 38	10 51	Direct.	−56 10	N.E.	+0 45	−6	−55 39	
			S.	−56 16					
			N.	−56 22					
			N.S.	−56 37					
			Direct.	−56 17					
26.	−45 32	11 54	Direct.	−56 03	N.E.	+0 44	−6	−55 19	
			S.	−56 07					
			N.	−55 44					
			N.S.	−55 57					
			Direct.	−55 55					
27.	−43 57	13 16	Direct.	−55 36	N.E. by E.	+0 39	−6	−54 28	
			S.	−55 24					
			N.	−55 20					
			N.S.	−55 51					
			Direct.	−55 35					
			wt. 2 grs.	−54 35					
			wt. 3 grs.	−54 10					
			wt. 4 grs.	−53 39					
28.	−43 10	14 44	Direct.	−55 33	N.E.	+0 42	−6	−54 40	
			S.	−55 43					
			N.	−55 49					
			N.S.	−55 52					
			Direct.	−55 25					
			wt. 2 grs.	−55 03					
			wt. 3 grs.	−54 16					
			wt. 4 grs.	−54 31					
29.	−41 40	15 09	Direct.	−55 14	N.E. ½ N.	+0 43	−6	−54 43	
			S.	−55 22					
			N.	−55 31					
			N.S.	−55 21					
			Direct.	−55 14					
30.	−40 15	15 47	Direct.	−55 24	N.E.	+0 42	−6	−54 50	
			S.	−55 31					
			N.	−55 11					
			N.S.	−55 31					
			Direct.	−55 31					
31.	−37 40	16 40	Direct.	−55 05	E.	+0 40	−6	−54 32	
			S.	−55 09					
			N.	−54 40					
			N.S.	−55 33					
			Direct.	−55 05					

Observations of Inclination, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Ship's head.	Corrections.		Corrected Inclination.		Remarks.
						Ship's attraction.	Index.			
1843. April 1.	−35° 59′	16° 34′	Direct.	−54° 45′						
			S.	−54 48						
			N.	−54 13	N.E. by E.	+0° 40′	−6′	−54° 06′		
			N.S.	−54 55						
			Direct.	−54 39						
2.	−35 26	16 22	Direct.	−53 51						
			S.	−54 03						
			N.	−53 08	E.	+0 11	−6	−53 45		
			N.S.	−54 21						
			Direct.	−53 47						
3.	−35 04	17 08	Direct.	−53 12	E. by S.	+0 02	−6	−53 16	−53° 24′	
			Direct.	−53 06	S.E. by E.	−0 19	−6	−53 31		
4.	Cape Point N.E. by E. distant six miles.		Direct.	−53 55						
			S.	−53 57	N.E. by E. ½ E.	+0 36	−6	−53 07		
			N.	−52 59						
			N.S.	−54 17	N.E. by E.	+0 37	−6	−53 46	−53 20	
			Direct.	−54 02	N.E. ½ E.	+0 38	−6	−53 30		
6.	Block House Point, Simon's Bay.		Direct.	−53 32						
			S.	−53 43						
			N.	−53 33						
	−34 11	18 26	N.S.	−53 42						
			wt. 1 gr.	−54 25						
			wt. 2 grs.	−53 47	Observed on shore.	......	−6	−53 40		
			wt. 3 grs.	−53 26						
			wt. 4 grs.	−52 50						
			S.	−53 19						
			N.	−53 10						
			N.S.	−53 43						

Observations of the Inclination, with Needles whose Poles were reversed, made on land or on the ice; in continuation of those recorded in Contribution VI., Philosophical Transactions, 1844, Art. VII., pp. 100–103. Station, St. Martin's Cove, near Cape Horn.

Date.	Needles.	Poles. "*a*" direct. "*b*" reversed.	Mean.	Remarks.
1842. Sept. 23.	R. 6	*a*—58° 08′·4	−58° 11′·9	Needles belonging to Her Majesty's Ship 'Erebus.'
		b—58 15·5		
	R. 4	*a*—58 19·8	−58 12·2	
		b—58 04·7		
	R. 7	*a*—58 11·4	−58 11·9	
		b—58 12·4		
27.	R. 4	*a*—58 18·9	−58 12·2	
		b—58 05·5		
30.	R. 4	*a*—58 17·3	−58 11·8	
		b—58 06·3		
Oct. 4.	R. 4	*a*—58 19·3	−58 12·5	
		b—58 05·7		
7.	R. 4	*a*—58 18·2	−58 11·7	
		b—58 05·3		
11.	R. 4	*a*—58 23·2	−58 14·2	
		b—58 05·3		
15.	R. 4	*a*—58 20·9	−58 13·4	
		b—58 05·8		
18.	R. 4	*a*—58 22·3	−58 13·8	
		b—58 05·3		
21.	R. 4	*a*—58 20·6	−58 14·1	
		b—58 07·6		
25.	R. 4	*a*—58 19·3	−58 12·3	
		b—58 05·2		
28.	R. 4	*a*—58 22·1	−58 14·6	
		b—58 07·0		
Nov. 1.	R. 4	*a*—58 19·1	−58 13·5	
		b—58 08·0		
4.	R. 4	*a*—58 21·5	−58 12·8	
		b—58 04·1		
Oct. 10.	C. 1	*a*—58 18·7	−58 13·0	Needles belonging to Her Majesty's Ship 'Terror.'
		b—58 07·2		
	C. 2	*a*—58 14·0	−58 11·2	
		b—58 08·4		
		General Mean	−58 12·8	

Observations of the Inclination, with Needles whose Poles were reversed, upon an Ice floe on January 2nd, 1843. Lat. —64° 26′. Long. 303° 52′.

Date.	Needles.	Poles. "*a*" direct. "*b*" reversed.	Mean.	Remarks.
1843. Jan. 2.	R. 4	*a*—63° 17′·3	−62° 12′·3	Needles belonging to Her Majesty's Ship 'Erebus.'
		b—63 07·3		
	R. 6	*a*—63 17·1	−63 20·2	
		b—63 23·2		
	R. 7	*a*—63 18·2	−63 19·1	
		b—63 20·0		
		Mean.........	−63 17·2	

Observations of the INCLINATION made in Her Majesty's Ship 'Terror' with Needle F. C. B., between September 1842 and April 1843.

Observers Captain FRANCIS RAWDON CROZIER and Mr. THOMAS E. L. MOORE, Mate, R.N.

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1842.	° ′	° ′									
Sept. 8.	Running out of Berkeley Sound, East Falklands.		Direct.	−51° 46′	E.	+0° 10′	−51° 36′	−51° 26′	−35′	−51° 51′	Very steady.
			Direct.	−51 12	E.S.E.	−0 10	−51 22				
			Direct.	−52 02	E. by N.	+0 27	−51 35				
	−52 32	301 53	Direct.	−50 48	S.E. by E.	−0 23	−51 11				
9.	−52 48	303 10	Direct.	−52 13	S.S.W.	−1 08	−53 17		−35	−53 52	Strong breeze, steering tolerably.
			Needle N.	−51 39							
			Needle S.	−52 19							
			Mag. N.	−52 15							
			Mag. N.S.	−52 19							
			Mag. S.	−52 13							Wind increasing, steering badly.
			Direct.	−52 10							
13.	−54 02	305 30	Direct.	−53 19	W. by N.	+0 15	−53 04		−35	−53 39	Very unsteady.
14.	−53 42	305 04	Direct.	−52 06	S.W. by S.	−0 58	−53 04		−35	−53 39	Very unsteady.
15.	−54 40	304 35	Direct.	−52 06	S.E. ½ S.	−0 43	−52 49		−35	−53 24	Much motion.
16.	−54 42	305 30	Direct.	−53 39	N.E.	+0 54	−52 45	−54 04	−35	−54 39	
			Direct.	−54 05	W. by S.	−0 07	−54 12				
			Direct.	−54 09	W.S.W.	−0 23	−54 32				Very unsteady.
			Needle N.	−54 18	W.S.W.		−54 41				Observations unsatisfactory.
			Needle S.	−54 31	W.S.W.		−54 54				
			Direct.	−54 06	W.S.W.		−54 29				
			Direct.	−53 40	W. by S.	−0 08	−53 48				
			Direct.	−53 15	W.	+0 01	−53 14				
17.	−55 10	301 00	Direct.	−54 55	S.W. by W.	−0 36	−55 31		−35	−56 06	Heavy sea.
18.	−55 30	297 00	Direct.	−56 07	S.W.	−0 56	−56 58		−35	−57 33	Steering well.
			Needle N.	−56 52							
			Needle S.	−55 41							
			Mag. N.	−55 57							
			Mag. N.S.	−55 49							
			Mag. S.	−55 50							
			Direct.	−56 00							
Oct. 3.	St. Martin's Cove, Cape Horn.		Direct.	−57 31	On shore ...	......	−57 28		−35	−58 03	
			Needle N.	−56 42							
	−55 51	292 28	Needle S.	−57 37							
			Mag. N.	−57 21							
			Mag. N.S.	−57 13							
			Mag. S.	−57 22							
			wt. 1 gr.	−57 25							
			wt. 1·5 gr.	−57 23							
			wt. 2 grs.	−57 27							
			wt. 2·5 grs.	−57 49							
			wt. 3 grs.	−57 34							
			wt. 3·5 grs.	−58 05							
			Direct.	−57 35							
4.	......	......	Direct.	−57 31							
Nov. 7.	Running out of St. Francis Bay.		Direct.	−57 34	S.E.	−0 44	−58 18	......	−35	−59 08	Steering well, slight motion.
			Direct.	−57 24	S.E. ½ S.	−0 51	−58 15				
	−56 02	292 57	Direct.	−59 43	E.N.E.	+0 47	−58 41				
			Needle N.	−58 55							
			Needle S.	−59 29							
			Direct.	−59 46							
8.	−55 52	295 41	Direct.	−57 48	N.E. by E.	+0 56	−56 43		−35	−57 18	Much motion.
			Needle N.	−57 03							
			Needle S.	−58 12							
			Mag. N.	−57 40							
			Mag. N.S.	−57 35							
			Mag. S.	−57 29							
			Direct.	−57 43							

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1842.											
Nov. 8.	−55° 38′	295° 54′	Direct.	−57° 27′	N.E. by E.	+0° 54′	−56° 33′	° ′	−35′	−57° 08′	
9.	−55 56	299 17	Direct.	−56 30	E. by N.	+0 29	−56 01		−35	−56 36	
10.	−55 28	298 35	Direct.	−55 49	S.W. ½ S.	−0 60	−56 49	−56 25	−35	−57 00	Much motion, steering well.
			Direct.	−55 24	S.W. ½ W.	−0 50	−56 14				
			Direct.	−56 20	W.	+0 08	−56 12				
11.	−55 05	299 49	Direct.	−56 53	N.	+0 67	−55 59		−35	−56 34	
			Needle N.	−56 58							
			Needle S.	−57 25							
			Mag. N.	−57 08							
			Mag. N.S.	−57 32							
			Mag. S.	−56 55							
			Direct.	−56 51							
	−54 40	301 32	Direct.	−56 44	N.	+1 04	−55 40		−35	−56 15	
	−54 36	301 37	Direct.	−56 38	N.	+1 04	−55 34		−35	−56 09	
12.	−52 26	301 16	Direct.	−54 07	N. by E.	+0 56	−53 04		−35	−53 39	
			Needle N.	−53 27							
			Needle S.	−54 15							
			Mag. N.	−54 01							
			Mag. N.S.	−54 16							
			Mag. S.	−54 00							
			Direct.	−54 04							
			Direct.	−53 53							
	−52 36	301 16	Direct.	−53 47	N. by E.	+0 56	−52 51		−35	−53 26	
16.	Port Louis,		Direct.	−51 27	On shore ...	......	−51 38		−35	−52 13	
	Falkland Islands.		Needle N.	−50 55							
			Needle S.	−51 39							
			Mag. N.	−51 16							
			Mag. N.S.	−51 17							
			Mag. S.	−51 24							
			wt. 1 gr.	−51 39							
			wt. 1·5 gr.	−51 36							
			wt. 2 grs.	−52 00							
			wt. 2·5 grs.	−52 20							
			wt. 3 grs.	−52 28							
Dec. 3.	Port Louis.		Direct.	−51 28	On shore ...	......	−51 43·5		−35	−52 18	
			Needle N.	−50 43							
			Needle S.	−51 45							
			Mag. N.	−51 17							
			Mag. N.S.	−51 17							
			Mag. S.	−51 27							
			wt. 1 gr.	−51 37							
			wt. 1·5 gr.	−51 51							
			wt. 2 grs.	−52 08							
			wt. 2·5 grs.	−52 29							
			wt. 3 grs.	−52 56							
4.	......	......	Direct.	−50 10	S. by E.	−1 03	−51 13	−51 25	−35	−52 00	
			Direct.	−50 08	S.	−1 09	−51 17				
7.	......	......	Direct.	−52 08	N.W. by W.	+0 29	−51 39				
8.	......	......	Direct.	−50 49	S.W.	−0 49	−51 38				
			Direct.	−51 13	W.S.W.	−0 22	−51 35				
			Direct.	−51 33	W.	+0 10	−51 23				
9.	......	......	Direct.	−51 18	W.N.W.	+0 19	−50 59				
			Direct.	−52 07	N.W.	+0 38	−51 29				
			Direct.	−50 59	S.E. by E.	−0 22	−51 21				
			Direct.	−51 29	E. by S.	0 00	−51 29				
			Direct.	−51 05	E.S.E.	−0 09	−51 14				
10.	......	......	Direct.	−50 18	S.S.W.	−1 05	−51 23				
			Direct.	−50 15	S. by W.	−1 06	−51 21				
			Direct.	−50 35	S.W. by S.	−0 57	−51 32				
11.	......	......	Direct.	−52 09	N.N.W.	+0 49	−51 20				
			Direct.	−52 14	N.W. by N.	+0 43	−51 31				
			Direct.	−52 10	N. by W.	+0 54	−51 16				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1842.		° ′		° ′		° ′	° ′	° ′	′	° ′	
Dec. 11.	……	……	Direct.	−52 15	N.	+0 54	−51 21	−51 25	−35	−52 00	
			Direct.	−52 02	N. by E.	+0 55	−51 07				
			Direct.	−51 48	W. by N.	+0 15	−51 33				
			Direct.	−51 42	W. by S.	−0 06	−51 48				
14.	……	……	Direct.	−50 18	S. by W.	−1 06	−51 24				
			Direct.	−50 36	S.W. by S.	−0 57	−51 33				
			Direct.	−51 33	W. by S.	−0 06	−51 39				
17.	Running out of Berkeley Sound.		Direct.	−51 44	N.E. by E.	+0 47	−50 57				
			Direct.	−51 49	E.N.E.	+0 44	−51 05				
	−51 32	301 53	Direct.	−51 50	E. by N.	+0 27	−51 23				
			Direct.	−51 31	E.	+0 10	−51 21				
			Direct.	−51 50	E. by N.	+0 27	−51 23				
			wt. 1 gr.	−51 18			−51 08				
			wt. 1·5 gr.	−51 27			−51 17				
			wt. 2 grs.	−51 45			−51 35				
			wt. 2·5 grs.	−52 02			−51 52				
			wt. 3 grs.	−52 09			−51 59				
			Direct.	−51 29	E.	+0 10	−51 19	−51 21	−35	−51 56	
			Needle N.	−50 49			−50 39				
			Needle S.	−51 31			−51 21				
			Mag. N.	−51 16			−51 06				
			Mag. N.S.	−51 22			−51 12				
			Mag. S.	−51 24			−51 14				
			Direct.	−51 28			−51 18				
			Direct.	−51 25	E. by S.	0 00	−51 25				
			Direct.	−51 07	E.S.E.	−0 09	−51 16				
			Direct.	−51 06	S.E. by E.	−0 22	−51 28				
			Direct.	−50 44	S.E.	−0 25	−51 09				
18.	−52 46	303 18	Direct.	−51 24							
			Needle N.	−50 54							
			Needle S.	−51 37							Steering badly; table very unsteady.
			Mag. N.	−51 14							
			Mag. N.S.	−51 23							
			Mag. S.	−51 22	S.E. by S.	−0 45	−52 14		−35	−52 49	
			wt. 1 gr.	−51 14							
			wt. 1·5 gr.	−51 52							
			wt. 2 grs.	−51 44							
			wt. 2·5 grs.	−51 48							
			wt. 3 grs.	−51 39							
			Direct.	−51 48							
	−52 52	303 20	Direct.	−51 59	E.S.E.	−0 09	−52 08		−35	−52 43	
19.	−53 38	303 43	Direct.	−51 44							
			Needle N.	−51 04							
			Needle S.	−51 38							
			Mag. N.	−51 36	S. by E.	−1 04	−52 36		−35	−53 11	Steering badly.
			Mag. N.S.	−51 37							
			Mag. S.	−51 34							
			Direct.	−51 32							
20.	−55 26	305 20	Direct.	−52 59							
			Needle N.	−52 11							
			Needle S.	−53 04							
			Mag. N.	−52 58	S.S.E.	−0 59	−53 57		−35	54 32	Table unsteady.
			Mag. N.S.	−53 14							
			Mag. S.	−53 07							
			Direct.	−53 16							
	−55 57	305 27	Direct.	−53 40							
			wt. 1 gr.	−53 58							
			wt. 1·5 gr.	−53 12	S.E. by S.	−0 50	−54 28		−35	−55 03	Steering very well.
			wt. 2 grs.	−53 58							
			wt. 2·5 grs.	−53 25							
			wt. 3 grs.	−53 37							
	−56 00	305 30	Direct.	−54 03	S.E. by S.	−0 50					

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1842. Dec. 20.	−56° 00′	305° 30′	Direct.	−53° 46′	S.S.E.	−1° 02′	−54° 40′		−35′	−55° 15′	Very steady.
			Needle N.	−53 12							
			Needle S.	−53 54							
			Mag. N.	−53 24							
			Mag. N.S.	−53 36							
			Mag. S.	−53 38							
			Direct.	−53 45							
21.	−56 55	306 40	Direct.	−54 38	S.S.E.	−1 04	−55 34		−35	−56 09	Steering badly.
			Needle N.	−53 38							
			Needle S.	−54 20							
			Mag. N.	−54 24							
			Mag. N.S.	−54 25							
			Mag. S.	−54 26							
			wt. 1 gr.	−54 49							
			wt. 1·5 gr.	−54 31							
			wt. 2 grs.	−54 53							
			wt. 2·5 grs.	−54 29							
			Direct.	−54 41							
	−57 00	306 42	Direct.	−54 49							
22.	−57 50	307 58	Direct.	−55 48	S.S.E.	−1 05	−56 46		−35	−57 19	Heavy sea; much motion.
			Needle N.	−55 29							
			Needle S.	−55 47							
			Direct.	−55 35	S. by E.	−1 12	−56 42				
			Mag. N.	−55 27							
			Mag. N.S.	−55 22							
			Mag. S.	−55 37							
			Direct.	−55 30							
	−58 25	307 53	Direct.	−55 41	S.S.E.	−1 06	−56 47	−56 39	−35	−57 14	Motion slight; steering well.
			wt. 1 gr.	−55 17	S. by E. ½ E.	−1 09	−56 26				
			wt. 1·5 gr.	−55 29	S. by E.	−1 12	−56 41				
			wt. 2 grs.	−55 23			−56 35				
			wt. 2·5 grs.	−55 46			−56 58				
			wt. 3 grs.	−55 06	S. by E. ½ E.	−1 09	−56 15				
			Direct.	−55 45	S. by E.	−1 12	−56 57				
			Needle N.	−54 49			−56 01				
			Needle S.	−55 22			−56 34				
			Mag. N.	−55 24			−56 36				
			Mag. N.S.	−55 39			−56 51				
			Mag. S.	−55 34			−56 46				
			Direct.	−55 42			−56 54				
23.	−59 44	308 02	Direct.	−57 07	S.S.W.	−1 18	−58 25	−57 58	−35	−58 33	
	−59 57	307 53	Direct.	−56 52	S. by W.	−1 18	−58 10				
			Needle N.	−56 19			−57 37				
			Needle S.	−56 33			−57 51				
			Mag. N.	−56 28			−57 46				
			Mag. N.S.	−56 35			−57 53				
			Mag. S.	−56 31			−57 49				
			Direct.	−56 53			−58 11				
24.	−61 20	307 42	Direct.	−58 12	S. by W.	−1 22	−59 12		−35	−59 47	Table very unsteady.
			Needle N.	−57 26							
			Needle S.	−58 03							
			Mag. N.	−57 59							
			Mag. N.S.	−58 00							
			Mag. S.	−57 59							
	−61 22	307 40	Direct.	−58 13							
25.	−62 12	307 47	Direct.	−59 04	S.S.E.	−1 14	−60 10		−35	−60 45	
			Needle N.	−58 22							
			Needle S.	−59 03							
			Mag. N.	−59 01							
			Mag. N.S.	−58 56							
			Mag. S.	−58 59							
			Direct.	−59 05							

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination		Index Correction.	True Inclination.	Remarks.
1842. Dec. 26.	−62° 25′	307° 58′	Direct.	−62° 27′	N.N.W.	+1° 06′	−61° 21′	−60° 19′	−35′	−60° 21′	Very steady; steering badly.
			Direct.	−61 29			−60 23				
			Needle N.	−60 32			−59 26				
			Needle S.	−61 24			−60 18				
			Mag. N.	−61 14			−60 08				
			Mag. N.S.	−61 24			−60 18				
			Mag. S	−61 23			−60 17				
			Direct.	−61 27			−60 21				
			wt. 1 gr.	−61 41	N.N.W. ½ W.	+1 02	−60 39	−60 24			
			wt. 1·5 gr.	−61 13			−60 11				
			wt. 2 grs.	−61 15			−60 13				
			wt. 2·5 grs.	−61 13			−60 11				
			wt. 3 grs.	−61 39			−60 37				
			Direct.	−61 27			−60 25				
			Direct.	−60 02	W.S.W.	−0 27	−60 29				
27.	−62 18	308 17	Direct.	−59 37	S.W.	−1 05	−60 42	−60 42	−35	−61 17	Table steady.
			Direct.	−60 20	W.S.W.	−0 27	−60 47				
			Needle N.	−59 38			−60 05				
			Needle S.	−60 27			−60 54				
			Mag. N.	−60 08			−60 35				
			Mag. N.S.	−60 04			−60 31				
			Mag. S.	−60 21			−60 48				
			wt. 1 gr.	−60 33			−61 00				
			wt. 1·5 gr.	−60 12			−60 39				
			wt. 2 grs.	−60 14			−60 41				
			wt. 2·5 grs.	−60 23			−60 50				
			wt. 3 grs.	−60 27			−60 54				
			Direct.	−60 16			−60 43				
28.	−62 30	306 52	Direct.	−61 18	W.S.W.	−0 27	−61 45	−61 29	−35	−62 04	Ship steady.
			Needle N.	−60 13			−60 40				
			Needle S.	−61 18			−61 45				
			Mag. N.	−60 57			−61 24				
			Mag. N.S.	−61 04			−61 31				
			Mag. S.	−60 59			−61 26				
			Direct.	−61 21			−61 48				
			Direct.	−60 29	S.W.	−1 01	−61 34				
	−62 42	305 27	Direct.	−60 11	S.W.	−1 05	−61 16	−61 12	−35	−61 47	Motion slight.
			Direct.	−60 12	S.W. ¼ W.	−0 57	−61 09				
			Needle N.	−59 27			−60 24				
			Needle S.	−60 19			−61 16				
			Mag. N.	−60 04			−61 01				
			Mag. N.S.	−60 06			−61 03				
			Mag. S.	−60 14			−61 11				
			wt. 1 gr.	−60 31			−61 28				
			wt. 1·5 gr.	−60 22			−61 19				
			wt. 2 grs.	−60 10			−61 07				
			wt. 2·5 grs.	−60 53			−61 50				
			Direct.	−60 21			−61 18				
29.	−63 13	305 33	Direct.	−61 02	S.E. by E.	−0 35	−61 37	−61 42	−35	−62 17	Steady; sailing among loose ice.
			Direct.	−60 58	S.E.	−0 50	−61 48				
	−63 35	305 47	Direct.	−62 23	N.E. by E. ½ E.	+0 52	−61 31	−61 56	−35	−62 31	Fresh breeze; unsteady.
			Direct.	−62 42	N.E.	+1 09	−61 33				
			Direct.	−62 21	E.S.E.	−0 20	−62 41				
			Direct.	−61 54	W. by S. ½ S.	−0 24	−62 18				
			Direct.	−61 16	S.W. by W.	−0 48	−62 04				
			Needle N.	−60 27			−61 15				
			Needle S.	−61 17			−62 05				
			Mag. N.	−60 58			−61 46				
			Mag. N.S.	−61 06			−61 54				
			Mag. S.	−61 15			−62 03				
			Direct.	−61 16			−62 04				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1842. Dec. 31.	−63° 57′	304° 32′	Direct.	−62° 12′	S.E. ½ E.	−0° 42′	−62° 54′	−62° 06′	−35′	−62° 41′	Steady; sea very smooth.
			Direct.	−60 53	S.	−1 30	−62 23				
			Needle N.	−59 53			−61 23				
			Needle S.	−60 36			−62 06				
			Mag. N.	−60 28			−61 58				
			Mag. N.S.	−60 36			−62 06				
			Mag. S.	−60 25			−61 55				
			wt. 1 gr.	−61 00			−62 30				
			wt. 1·5 gr.	−60 32			−62 02				
			wt. 2 grs.	−60 27			−61 57				
			wt. 2·5 grs.	−60 39			−62 09				
			wt. 3 grs.	−60 24			−61 54				
1843. Jan. 1.	−64 15	304 25	Direct.	−63 02	W.	+0 07	−62 55	−62 53	−35	−63 28	Very steady.
			Direct.	−63 49	N.W. by W.	+0 46	−63 03				
			Direct.	−63 29	W.N.W.	+0 32	−62 57				
			Direct.	−63 53	N.W. by N.	+1 05	−62 48				
			Direct.	−61 31	S.S.E.	−1 17	−62 48				
			Direct.	−61 58	S.E.	−0 50	−62 48				
			Direct.	−61 46	S.E. by S.	−1 03	−62 49				
2.	−64 27	303 54	Direct.	−63 01	On ice	......	−62 46		−35	−63 21	Dip on the ice with needles whose poles were reversed, −63° 17′.
			Needle N.	−62 06							
			Needle S.	−63 05							
			Mag. N.	−62 45							
			Mag. N.S.	−62 48							
			Mag. S.	−62 38							
			wt. 1 gr.	−62 45							
			wt. 1·5 gr.	−62 44							
			wt. 2 grs.	−62 48							
			wt. 2·5 grs.	−62 52							
			wt. 3 grs.	−62 52							
3.	−64 26	303 54	Direct.	−64 02	N.W. by N.	+1 07	−62 55	−62 36	−35	−63 11	Steady; sailing amongst loose ice.
			Direct.	−63 31	E. by N.	+0 29	−63 02				
			Direct.	−63 28	N.W. ½ W.	+0 47	−62 41				
			Needle N.	−62 21			−61 34				
			Needle S.	−63 32			−62 45				
			Mag. N.	−63 18			−62 31				
			Mag. N.S.	−63 06			−62 19				
			Mag. S.	−63 18			−62 31				
			Direct.	−63 34			−62 47				
			Direct.	−63 44	N.W. by W.	+0 46	−62 58				
4.	−64 06	303 43	Direct.	−63 34	N.E.	+1 10	−62 24	−62 47	−35	−63 22	
			Direct.	−63 44	N.W. by W. ½ W.	+0 40	−63 04				
			Direct.	−63 42	N.W. ½ W.	+0 53	−62 49				
			Needle N.	−62 56	N.W. by W. ½ W.	+0 39	−62 17				
			Needle S.	−63 18			−62 39				
			Mag. N.	−63 24			−62 45				
			Mag. N.S.	−63 17			−62 38				
			Mag. S.	−63 34			−62 55				
			Direct.	−63 44			−63 05				
			Direct.	−63 42	W.N.W.	+0 33	−63 09				
	−64 36	304 26	Direct.	−63 56	N. by W.	+1 18	−62 38	−62 19	−35	−62 54	
			Direct.	−63 46	N. by E.	+1 20	−62 26				
			wt. 1 gr.	−63 41			−62 21				
			wt. 1·5 gr.	−63 37			−62 17				
			wt. 2 grs.	−63 23			−62 03				
			wt. 2·5 grs.	−63 39			−62 19				
			wt. 3 grs.	−63 23	N.N.E. ½ E.	+1 18	−62 05				
			wt. 3·5 grs.	−63 36	N.N.E.	+1 20	−62 16				
			Direct.	−63 44	N. by E. ½ E.	+1 20	−62 24				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Jan. 5.	−64° 13′	304° 06′	Direct.	−63° 04′	W. by N. ½ N.	+0° 26′	−62° 38′	−62° 38′	−35′	−63° 13′	
			Direct.	−62 51	W.	+0 07	−62 44				
			Needle N.	−62 00			−61 53				
			Needle S.	−63 00			−62 53				
			Mag. N.	−62 54			−62 47				
			Mag. N.S.	−62 59			−62 52				
			Mag. S.	−62 45			−62 38				
			Direct.	−63 17	W.N.W.	+0 33	−62 44				
			Direct.	−63 06			−62 33				
	−64 13	304 06	Direct.	−63 06	E. by N.	+0 29	−62 37	−62 25	−35	−63 00	
			wt. 1 gr.	−62 34			−62 05				
			wt. 1·5 gr.	−63 22	N.E. ½ N.	+1 12	−62 10				
			wt. 2 grs.	−63 37	N.	+1 22	−62 15				
			wt. 2·5 grs.	−63 59			−62 37				
			wt. 3 grs.	−63 46			−62 24				
			wt. 3·5 grs.	−63 55			−62 33				
			Direct.	−63 44			−62 22				
			Direct.	−62 36	E. by S.	−0 06	−62 42				
6.	−64 12	303 04	Direct.	−63 17	W.	+0 07	−63 10	−62 49	−35	−63 24	
			Needle N.	−62 06			−61 59				
			Needle S.	−63 08			−63 01				
			Mag. N.	−62 58			−62 51				
			Mag. N.S.	−62 58			−62 51				
			Mag. S.	−62 55			−62 48				
			Direct.	−63 02			−62 55				
			Direct.	−61 31	S. by E.	−1 23	−62 54				
7.	−64 36	302 52	Direct.	−61 51	S. ½ W.	−1 30	−63 21	−63 01	−35	−63 36	
			Needle N.	−60 45			−62 15				
			Needle S.	−61 45			−63 15				
			Mag. N.	−61 29			−62 59				
			Mag. N.S.	−61 26			−62 56				
			Mag. S.	−61 29			−62 59				
			Direct.	−61 50			−63 20				
	−64 36	302 32	Direct.	−61 35	S.S.E.	−1 18	−62 53	−63 16	−35	−63 51	Sailing amongst loose ice.
			Direct.	−63 43	N.W. by W. ½ W.	+0 40	−63 03				
			wt. 1 gr.	−64 03	W.N.W.	+0 34	−63 29				
			wt. 1·5 gr.	−61 53	S. ½ W.	−1 32	−63 25				
			wt. 2 grs.	−61 31			−63 03				
			wt. 2·5 grs.	−61 40			−63 12				
			wt. 3 grs.	−61 53			−63 25				
			wt. 3·5 grs.	−62 06			−63 38				
8.	−64 37	303 10	Direct.	−61 50	S. by E.	−1 26	−63 16	−63 03	−35	−63 38	Very steady.
			Direct.	−62 24			−63 50				
			Direct.	−62 30	S.E. by E.	−0 38	−63 08				
			Needle N.	−61 33			−62 11				
			Needle S.	−62 23			−63 01				
			Mag. N.	−62 18			−62 56				
			Mag. N.S.	−62 19			−62 57				
			Mag. S.	−62 23			−63 01				
			Direct.	−62 33			−63 11				
	−64 37	303 10	wt. 1 gr.	−62 47	E.S.E.	−0 21	−63 08	−63 13	−35	−63 48	
			wt. 1·5 gr.	−62 48			−63 09				
			wt. 2 grs.	−62 58			−63 19				
			wt. 2·5 grs.	−62 50			−63 11				
			wt. 3 grs.	−62 52			−63 13				
			wt. 3·5 grs.	−63 00			−63 21				
			Direct.	−62 47			−63 08				
	−64 44	303 07	Direct.	−63 15	On ice ……	……	−63 09		−35	−63 44	
			Needle N.	−62 19							
			Needle S.	−63 12							
			Mag. N.	−63 31							
			Mag. N.S.	−63 01							
			Mag. S.	−63 00							

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Jan. 8.	−64° 44′	303° 07′	wt. 1 gr.	−63° 11′	On ice	° ′	−63° 09′		−35′	−63° 44′	
			wt. 1·5 gr.	−63 08							
			wt. 2 grs.	−62 57							
			wt. 2·5 grs.	−63 11							
			wt. 3 grs.	−63 21							
			wt. 3·5 grs.	−63 31							
			Direct.	−63 18							
10.	−64 40	303 08	Direct.	−62 32	s.w. by w.	−0 49	−63 21	−63° 17′	−35	−63 52	
			Direct.	−62 22	s.w.	−1 08	−63 30				
			Direct.	−62 16	s.w. by s.	−1 16	−63 32				
			Needle N.	−61 23			−62 39				
			Needle S.	−62 11			−63 27				
			Mag. N.	−62 03			−63 19				
			Mag. N.S.	−62 01			−63 17				
			Mag. S.	−61 56			−63 12				
11.	−64 35	303 06	Direct.	−62 42	s.e. by e.	−0 38	−63 20		−35	−63 55	
12.	−64 36	302 07	Direct.	−62 16	s. ½ w.	−1 30	−63 46	−63 31	−35	−64 06	
			Direct.	−62 10	s. by w.	−1 31	−63 41				
			Direct.	−63 48	w. by n. ½ n.	+0 26	−63 22				
			Direct.	−64 09	n.w.	+1 00	−63 09				
			Direct.	−62 23	s.s.e.	−1 18	−63 41				
			Direct.	−64 02	w.n.w.	+0 34	−63 28				
	−64 36	302 07	Mag. N.	−63 42	w.n.w.	+0 34	−63 08	−63 23	−35	−63 58	Sailing amongst loose ice.
			Direct.	−63 45	w.	+0 07	−63 38				
			Mag. N.S.	−63 17			−63 10				
			Direct.	−62 31	s.e.	−0 54	−63 25				
			Direct.	−63 06	e.s.e.	−0 22	−63 28				
			Direct.	−64 04	w.n.w.	+0 34	−63 30				
			Direct.	−63 40	w.	+0 07	−63 33				
			Direct.	−62 53	e.s.e.	−0 22	−63 15				
13.	−64 42	302 42	Direct.	−62 03	s. by w.	−1 31	−63 34	−63 20	−35	−63 55	
			Direct.	−64 05	n.w.	+1 00	−63 05				
14.	−64 34	302 43	Direct.	−63 24	w.	+0 07	−63 17	−63 14	−35	−63 49	
			Direct.	−62 16	s.e.	−0 54	−63 10				
			Direct.	−61 51	s.s.e.	−1 19	−63 10				
			Direct.	−63 46	w. by n.	+0 20	−63 26				
			Direct.	−62 35	s.e. by e. ½ e.	−0 30	−63 05				
16.	−64 26	303 05	Direct.	−63 56	n.n.w.	+1 17	−62 39	−62 29	−35	−63 04	Fast to a floe.
			Needle N.	−63 02			−61 45				
			Needle S.	−63 54			−62 37				
			Mag. N.	−63 43			−62 26				
			Mag. N.S.	−63 40			−62 23				
			Mag. S.	−63 44			−62 27				
			Direct.	−64 00			−62 43				
			Direct.	−63 21	e. by n.	+0 28	−62 53				
	−64 28	303 03	Direct.	−63 05	On ice	......	−63 05		−35	−63 40	
17.	−64 22	303 30	Direct.	−63 59	n.e. ½ e.	+1 05	−62 54		−35	−63 29	
18.	−64 56	305 25	Direct.	−63 06	n.e. by e.	+1 01	−62 05	−61 53	−35	−62 28	Amongst loose ice.
			Needle N.	−62 14			−61 13				
			Needle S.	−63 00			−61 59				
			Mag. N.	−62 51			−61 50				
			Mag. N.S.	−62 48			−61 47				
			Mag. S.	−62 54			−61 53				
			Direct.	−63 13	n.e.	+1 10	−62 03				
			wt. 1 gr.	−62 52	n.e. ½ e.	+1 05	−61 47				
			wt. 1·5 gr.	−62 53			−61 48				
			wt. 2 grs.	−62 52			−61 47				
			wt. 2·5 grs.	−63 01			−61 56				
			wt. 3 grs.	−63 15			−62 10				
			wt. 3·5 grs.	−63 17			−62 12				
	−64 00	305 24	Direct.	−62 35	e. ½ n.	+0 20	−62 15		−35	−62 50	
19.	−64 22	305 44	Direct.	−62 45	e. by s.	−0 06	−62 51	−62 54	−35	−63 29	
			Direct.	−62 52			−62 58				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Jan. 20.	−64° 16′	304° 26′	Direct.	−62° 39′	W. by S. ½ S.	−0° 24′	−63° 03′	−62° 51′	−35′	−63° 26′	
			Needle N.	−61 50			−62 14				
			Mag. N.	−62 33			−62 57				
			Mag. N.S.	−62 27			−62 51				
			Mag. S.	−62 26			−62 50				
			Direct.	−62 39			−63 03				
			Direct.	−62 08	S.E. by E.	−0 38	−62 46				
			Direct.	−62 54	W. ½ S.	−0 03	−62 57				
			Direct.	−62 30	W.S.W.	−0 30	−63 00				
21.	−64 18	304 13	Direct.	−62 24	E.S.E.	−0 21	−62 45	−62 39	−35	−63 14	
			Needle N.	−61 22			−61 43				
			Needle S.	−62 13			−62 34				
			Mag. N.	−62 10			−62 31				
			Mag. N.S.	−62 03			−62 24				
			Direct.	−62 55	W.	+0 07	−62 48				
			Mag. S.	−62 57			−62 50				
			Direct.	−62 55	W. by S.	−0 18	−63 13				
			Direct.	−62 50	E.	+0 09	−62 41				
			Direct.	−62 14	S.E. by E.	−0 36	−62 50				
			Direct.	−62 17	W.S.W.	−0 30	−62 47				
22.	−64 12	304 07	Direct.	−63 22	N.W.	+0 59	−62 23	−62 29	−35	−63 04	
			Direct.	−62 45	E. by N.	+0 28	−63 17				
			Direct.	−63 07	E.N.E.	+0 51	−62 16				
			wt. 1 gr.	−63 14			−62 23				
			wt. 1·5 gr.	−62 55			−62 04				
			wt. 2 grs.	−63 08			−62 17				
			wt. 2·5 grs.	−63 23	N.W.	+0 59	−62 24				
			wt. 3 grs.	−63 33			−62 34				
			wt. 3·5 grs.	−63 37			−62 38				
			Direct.	−63 31			−62 30				
			Direct.	−62 47	E.	+0 09	−62 38				
23.	−64 20	304 08	Direct.	−63 25	W.N.W.	+0 33	−62 52	−62 45	−35	−63 20	
			Direct.	−63 44	N.W. by N.	+1 07	−62 37				
			Direct.	−62 24	E.S.E.	−0 21	−62 45				
			Direct.	−62 52	E.	+0 09	−62 43				
			Direct.	−62 42	E. by S.	−0 06	−62 48				
			Direct.	−63 32	N.W. by W.	+0 46	−62 46				
24.	−64 16	304 44	Direct.	−62 15	S.E. by E.	−0 35	−62 50	−62 20	−35	−62 55	Amongst loose ice.
			Direct.	−63 42	N.	+1 22	−62 20				
			Direct.	−63 44	N. by W.	+1 18	−62 26				
			Direct.	−63 42	N. ½ E.	+1 21	−62 21				
			Needle N.	−62 52			−61 31				
			Needle S.	−63 47			−62 26				
			Mag. N.	−63 31			−62 10				
			Mag. N.S.	−63 29			−62 08				
			Mag. S.	−63 33			−62 12				
			Direct.	−63 44	N.	+1 22	−62 22				
			Direct.	−61 53	S.E. by S.	−1 05	−62 58				
25.	−64 16	304 17	Direct.	−61 25	S.S.E. ½ E.	−1 11	−62 36	−62 45	−35	−63 20	
			Direct.	−63 02	W.	+0 07	−62 55				
26.	−64 01	304 20	Direct.	−61 43	S.E.	−0 52	−62 35	−62 28	−35	−63 02	
			Needle N.	−60 54			−61 46				
			Needle S.	−61 30			−62 22				
			Mag. N.	−61 17			−62 09				
			Direct.	−62 54	W.	+0 07	−62 47				
			Mag. N.S.	−62 41			−62 34				
			Mag. S.	−62 44			−62 37				
			Direct.	−62 58			−62 51				
28.	−64 14	304 04	Direct.	−62 28	E. by S.	−0 06	−62 34		−35	−63 09	

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Jan. 28.	−64° 09′	304° 06′	Direct.	−63° 15′	N.E. by E.	+1° 00′	−62° 15′	−62° 38′	−35′	−63° 13′	
			Direct.	−61 50	S.W.	−1 07	−62 57				
			Needle N.	−60 56			−62 03				
			Needle S.	−61 48			−62 55				
			Mag. N.	−61 44			−62 51				
			Mag. N.S.	−61 38			−62 45				
29.	−64 08	304 02	Direct.	−61 43	S. by E.	−1 29	−63 12	−62 39	−35	−63 14	
			Direct.	−62 42	E. by S.	−0 08	−62 50				
			Direct.	−63 32	N. by W.	+1 18	−62 14				
			Direct.	−63 35	N.N.W.	+1 15	−62 20				
30.	−64 07	303 58	Direct.	−62 25	E. by S.	−0 06	−62 31	−62 32	−35	−63 07	
			Direct.	−62 18	E.S.E.	−0 21	−62 39				
			Direct.	−63 35	N.W. by N.	+1 07	−62 28				
			Direct.	−63 23	N.W. by W.	+0 46	−62 37				
			Direct.	−63 29	N.W.	+0 59	−62 30				
			Direct.	−62 45	E. ¼ N.	+0 19	−62 26				
31.	−64 01	304 42	Direct.	−62 35	E.	+0 09	−62 26	−62 09	−35	−62 44	
			Direct.	−62 52	N.E. by E.	+1 00	−61 52				
Feb. 1.	−64 00	304 47	Direct.	−62 32	W. ½ S.	−0 02	−62 34	−62 26	−35	−63 01	Sailing amongst loose ice.
			Needle N.	−61 34			−61 36				
			Needle S.	−62 26			−62 28				
			Mag. N.	−62 12			−62 14				
			Mag. N.S.	−62 17			−62 19				
			Mag. S.	−62 20			−62 22				
			Direct.	−63 01	W.N.W.	+0 33	−62 28				
			Direct.	−61 08	S. by E. ½ E.	−1 21	−62 29				
			Direct.	−61 18	S.E. by S.	−1 04	−62 22				
2.	−64 19	304 43	Direct.	−62 29	E. ½ S.	+0 02	−62 27	−62 37	−35	−63 12	
			Direct.	−62 34	W. by S.	−0 11	−62 45				
			wt. 1 gr.	−62 18			−62 29				
			wt. 1·5 gr.	−62 29			−62 40				
			wt. 2 grs.	−62 11			−62 22				
			wt. 2·5 grs.	−62 24			−62 35				
			wt. 3 grs.	−62 25			−62 36				
			wt. 3·5 grs.	−62 45			−62 56				
			Direct.	−62 33			−62 44				
	−64 17	304 41	Direct.	−62 13	W.S.W.	−0 29	−62 42	−62 26	−35	−63 01	
			Direct.	−62 33	E.	+0 09	−62 24				
			Direct.	−62 42	E. by N.	+0 29	−62 13				
3.	−64 18	305 40	Direct.	−61 32	S.E.	−0 51	−62 23	−62 33	−35	−63 08	
			Direct.	−63 32	N.E. by N.	+1 15	−62 17				
			Direct.	−61 18	S.	−1 32	−62 50				
			Direct.	−61 23	S.S.E.	−1 17	−62 40				
4.	−64 12	305 17	Direct.	−61 28	S.S.W.	−1 26	−62 54	−62 14	−35	−62 49	Table steady; swell.
			Direct.	−63 18	E.N.E.	+0 50	−62 28				
			Needle N.	−62 12			−61 22				
			Needle S.	−63 03			−62 13				
			Direct.	−63 13	N.E.	+1 10	−62 03				
			Direct.	−63 04	E. by N.	+0 29	−62 35				
			Direct.	−63 23	N.N.E. ½ E.	+1 18	−62 05				
	−64 11	305 13	Direct.	−61 55	S.W.	−1 07	−63 02	−62 23	−35	−62 58	
			Direct.	−63 03	N.N.E.	+1 20	−61 43				
5.	−63 39	306 51	Direct.	−62 27	N.E. by E.	+1 00	−61 27	−61 18	−35	−61 53	
	−63 29	307 08	Direct.	−62 18	N.E.	+1 10	−61 08				
6.	−63 42	307 23	Direct.	−62 38	N. by E.	+1 18	−61 20	−61 47	−35	−62 22	Heavy head sea; very unsteady.
	−63 31	307 48	Direct.	−60 34	S. by E.	−1 30	−62 04				
			Needle N.	−59 37			−61 07				
			Needle S.	−60 19			−61 49				
			Mag. N.	−60 19			−61 49				
			Mag. N.S.	−60 28			−61 58				
			Mag. S.	−60 19			−61 49				
			Direct.	−60 47			−62 17				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Feb. 7.	−63° 56′	308° 00′	Direct.	−60° 57′	S.E. by S.	−1° 02′	−61° 59′	−61° 37′	−35′	−62° 12′	
			Needle N.	−59 58			−61 00				
			Needle S.	−60 40			−61 42				
			Mag. N.	−60 38			−61 40				
			Mag. N.S.	−60 26			−61 28				
			Mag. S.	−60 31			−61 33				
			Direct.	−60 53			−61 55				
	−64 05	308 03	Direct.	−60 46	S.S.E.	−1 15	−62 01	−60 56	−35	−61 31	Heavy head sea; very unsteady.
			Direct.	−62 30	N. by E. ½ E.	+1 18	−61 12				
			Direct.	−62 18	N. ½ E.	+1 18	−61 00				
			Needle N.	−61 10			−59 52				
			Needle S.	−62 07			−60 49				
			Mag. N.	−62 10			−60 52				
			Mag. N.S.	−62 02			−60 44				
			Mag. S.	−62 15			−60 57				
8.	−63 49	308 52	Direct.	−61 47	E. ½ N.	+0 19	−61 28		−35	−62 03	
9.	−64 18	309 40	Direct.	−61 18	E.S.E.	−0 18	−61 36	−61 33	−35	−62 08	Slight motion.
			Direct.	−61 34	E. by S.	−0 05	−61 39				
			wt. 1 gr.	−61 19			−61 24				
			wt. 1·5 gr.	−61 41			−61 46				
			wt. 2 grs.	−61 22			−61 27				
			wt. 2·5 grs.	−61 44			−61 49				
			wt. 3 grs.	−61 52			−61 57				
			wt. 3·5 grs.	−61 56			−62 01				
			Direct.	−61 33			−61 38				
			Needle N.	−60 33			−60 38				
			Needle S.	−61 33			−61 38				
			Mag. N.	−61 24			−61 29				
			Mag. N.S.	−61 09			−61 14				
			Mag. S.	−61 14			−61 19				
			Direct.	−61 33			−61 38				
10.	−64 43	312 06	Direct.	−62 18	N.E.	+1 09	−61 09	−61 21	−35	−61 56	A little motion.
			Direct.	−62 27	E.N.E.	+0 50	−61 37				
			Needle N.	−61 43			−60 53				
			Needle S.	−62 30			−61 40				
			Mag. N.	−62 17			−61 27				
			Mag. N.S.	−61 51			−61 01				
			Mag. S.	−62 20			−61 30				
			Direct.	−62 02	E. by N.	+0 29	−61 33				
11.	−64 38	314 01	Direct.	−62 29	N.	+1 20	−61 09	−61 09	−35	−61 44	Fresh breeze; much motion.
			Direct.	−62 26	N. by E.	+1 19	−61 07				
			Needle N.	−61 40			−60 21				
			Neecle S.	−62 15			−60 56				
			Mag. N.	−62 22			−61 03				
			Mag. N.S.	−62 19			−61 00				
			Mag. S.	−62 59			−61 40				
			Direct.	−61 06	S.E. ½ S.	−0 56	−62 02				
			Direct.	−62 15	N.E.	+1 09	−61 06				
12.	−64 49	315 07	Direct.	−62 05	E.S.E.	−0 20	−62 25	−60 59	−35	−61 34	Little motion.
			Direct.	−62 14	N.E. ½ E.	+1 04	−61 10				
			Direct.	−62 03	N.E. by E.	+0 59	−61 04				
			Direct.	−61 54	E.N.E.	+0 50	−61 04				
			Needle N.	−60 51			−60 01				
			Needle S.	−61 51			−61 01				
			Direct.	−61 59	N.E. by E.	+0 59	−61 00				
			Mag. N.	−61 40			−60 41				
			Mag. N.S.	−61 39			−60 40				
			Mag. S.	−61 44			−60 45				
13.	−64 47	316 57	Direct.	−60 14	S. by E. ½ E.	−1 20	−61 34	−61 44	−35	−62 19	Slight motion.
			Needle N.	−59 02			−60 22				
			Needle S.	−59 52			−61 12				
			Mag. N.	−59 55			−61 15				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Feb. 13.	−64° 47′	316° 57′	Direct.	−61° 11′	S. by E. ½ E.	−1° 20′	−62° 31′	−61° 44′	−35′	−62° 19′	Slight motion.
			Direct.	−61 25			−62 45				
			Direct.	−61 31	E.S.E.	−0 20	−61 51				
			Direct.	−62 00	S.E.	−0 50	−62 50				
			Direct.	−62 32	N.	+1 20	−61 12				
14.	−64 58	318 26	Direct.	−61 41	E.	+0 09	−61 32	−61 13	−35	−61 48	Steering well.
			wt. 1 gr.	−61 46			−61 37				
			wt. 1·5 gr.	−61 22			−61 13				
			wt. 2 grs.	−61 23			−61 14				
			wt. 2·5 grs.	−61 15			−61 06				
			wt. 3 grs.	−61 35			−61 26				
			wt. 3·5 grs.	−61 49			−61 40				
			Direct.	−61 31			−61 22				
			Needle N.	−60 14			−60 05				
			Needle S.	−61 18			−61 09				
			Mag. N.	−61 14			−61 05				
			Mag. N.S.	−61 14			−61 05				
			Needle S.	−61 15			−61 06				
			Direct.	−61 38			−61 29				
			Direct.	−61 51	E. by N.	+0 30	−61 21				
			Direct.	−61 59	E.N.E.	+0 50	−61 09				
15.	−64 37	320 28	Direct.	−61 55	N.E.	+1 09	−60 46	−60 25	−35	−61 00	Strong breeze; unsteady; steering badly.
			Direct.	−62 04	N.E. by N.	+1 12	−60 52				
			Direct.	−62 08	N.N.E.	+1 18	−60 50				
			Direct.	−61 50	N.E.	+1 09	−60 41				
			Needle N.	−60 37			−59 28				
			Needle S.	−61 26			−60 17				
			Mag. N.	−61 17			−60 08				
			Mag. N.S.	−61 27			−60 18				
16.	−64 02	321 55	Direct.	−60 50	N.E. by E.	+0 58	−59 52	−59 58	−35	−60 33	Strong breeze; head sea; very unsteady.
			Direct.	−59 08	S.W.	−1 04	−60 12				
			Needle N.	−58 03			−59 07				
			Needle S.	−58 59			−60 03				
			Mag. N.	−58 51			−59 55				
			Mag. N.S.	−58 52			−59 56				
			Direct.	−59 15	S.W. by W. ½ W.	−0 37	−59 52				
			Mag. S.	−59 00			−59 37				
			Direct.	−59 20	S.S.W.	−1 22	−60 42				
			Direct.	−60 35	E.	+0 09	−60 26				
17.	−63 59	324 18	Direct.	−60 02	E.	+0 09	−59 53	−59 26	−35	−60 01	Moderate breeze; ship unsteady.
			Needle N.	−59 00			−58 51				
			Needle S.	−59 59			−59 50				
			Mag. N.	−60 00			−59 51				
			Mag. N.S.	−60 08			−59 59				
			Direct.	−60 48	N.	+1 15	−59 33				
			Direct.	−60 29	N.N.W.	+1 08	−59 21				
18.	−62 37	328 17	Direct.	−59 12	E.N.E.	+0 48	−58 24	−58 17	−35	−58 52	Moderate breeze; little motion.
			Direct.	−59 21	N.E. ½ E.	+1 02	−58 19				
			Needle N.	−58 23			−57 21				
			Needle S.	−59 29			−58 27				
			Direct.	−59 05	E. by N.	+0 29	−58 36				
			Mag. N.	−58 43			−58 14				
			Mag. N.S.	−58 45			−58 16				
			Mag. S.	−58 49			−58 20				
			Direct.	−59 05			−58 36				
19.	−62 13	330 38	Direct.	−58 31	E.N.E.	+0 47	−57 44				
			Direct.	−58 23	E. by N.	+0 29	−57 54				
			wt. 1 gr.	−58 32			−58 03				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Feb. 19.	-62° 13′	330° 38′	wt. 1·5 gr.	-58° 14′	E.	+0° 10′	-58° 04′	-57° 55′	-35′	-58° 30′	Table unsteady.
			wt. 2 grs.	-57 48			-57 38				
			wt. 2·5 grs.	-58 05			-57 55				
			Direct.	-58 23			-58 13				
			Needle N.	-57 23			-57 13				
			Mag. N.S.	-58 14			-58 04				
			Mag. S.	-58 20			-58 10				
			Direct.	-57 43	E.S.E.	-0 17	-58 00				
			Direct.	-58 02	E. by S.	-0 03	-58 05				
20.	-62 05	333 38	Direct.	-58 40	N. by E.	+1 10	-57 30	-57 22	-35	-57 57	Table unsteady.
			Needle N.	-57 46			-56 36				
			Needle S.	-58 55			-57 45				
			Mag. N.	-58 36			-57 26				
			Mag. N.S.	-58 27			-57 17				
			Direct.	-58 33	N.N.E.	+1 09	-57 24				
			Direct.	-58 27	N.E.	+1 02	-57 25				
			Mag. N.S.	-58 17			-57 15				
			Direct.	-58 29			-57 18				
			Direct.	-56 18	S.	-1 21	-57 39				
21.	-61 32	336 10	Direct.	-57 44	E.	+0 10	-57 34	-57 26	-35	-58 01	Strong breeze; ship unsteady.
			Needle N.	-57 05			-56 55				
			Needle S.	-58 06			-57 56				
			Mag. N.	-57 31			-57 21				
			Mag. N.S.	-57 35			-57 25				
			Mag. S.	-57 31			-57 21				
			Direct.	-57 38			-57 28				
22.	-61 28	337 42	Direct.	-56 44	S.W. ½ W.	-0 52	-57 36	-57 25	-35	-58 00	Motion slight.
			Needle N.	-55 27			-56 19				
			Needle S.	-56 37			-57 29				
			Mag. N.	-56 32			-57 24				
			Direct.	-57 03	W.S.W.	-0 26	-57 29				
			Direct.	-56 54	S.E. by E. ½ E.	-0 23	-57 17				
			Mag. N.S.	-56 36			-56 59				
			wt. 1 gr.	-56 53	E.S.E.	-0 16	-57 09				
			wt. 1·5 gr.	-56 53			-57 09				
			wt. 2 grs.	-57 08			-57 24				
			wt. 2·5 grs.	-57 10	S.E. by E.	-0 30	-57 40				
			wt. 3 grs.	-56 58			-57 28				
			wt. 3·5 grs.	-58 25			-58 55				
			Direct.	-56 44	S.E. ½ S.	-0 48	-57 32				
			Direct.	-56 52	S.E.	-0 43	-57 35				
23.	-61 13	340 00	Direct.	-57 27	E.	+0 10	-57 17	-57 22	-35	-57 57	Strong breeze; much motion.
			Direct.	-57 05	S.E. by E. ½ E.	-0 23	-57 28				
24.	-62 41	343 18	Direct.	-56 58	S.	-1 24	-58 22	-58 26	-35	-59 01	Light breeze; little motion.
			Direct.	-57 17	S. ½ E.	-1 20	-58 37				
			Needle N.	-56 24			-57 44				
			Needle S.	-57 16			-58 36				
			Mag. N.	-57 06			-58 26				
			Mag. N.S.	-57 14			-58 34				
			Mag. S.	-57 11			-58 31				
			wt. 1 gr.	-57 15			-58 35				
			wt. 1·5 gr.	-57 00			-58 20				
			wt. 2 grs.	-57 19			-58 39				
			wt. 2·5 grs.	-56 47			-58 07				
			wt. 3 grs.	-57 01			-58 21				
			Direct.	-57 23			-58 43				
25.	-64 14	345 30	Direct.	-61 06	E.N.E.	+0 48	-60 18	-60 10	-35	-60 45	Strong breeze; very unsteady.
			Needle N.	-60 15			-59 27				
			Needle S.	-61 06			-60 18				
			Mag. N.	-60 58			-60 10				
			Mag. N.S.	-61 01			-60 13				
			Mag. S.	-61 03			-60 15				
			Direct.	-60 56	E. by N.	+0 29	-60 27				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Feb. 26.	-64° 33′	347° 52′	Direct.	-60° 51′	E.	+0° 10′	-60° 41′	-60° 53′	-35′	-61° 28′	Much swell; unsteady.
			Direct.	-60 13	S.E.	-0 46	-60 59				
			Needle N.	-59 31			-60 17				
			Needle S.	-59 57			-60 43				
			Mag. N.	-60 29			-61 15				
			Mag. N.S.	-60 25			-61 11				
			Mag. S.	-60 10			-60 56				
			Direct.	-60 18			-61 04				
27.	-65 00	349 30	Direct.	-59 46	S.S.E.	-1 15	-61 01	-61 04	-35	-61 39	Steering well.
			Needle N.	-59 19			-60 34				
			Needle S.	-60 00			-61 15				
			Mag. N.	-59 56			-61 11				
			Mag. N.S.	-59 51			-61 06				
			Mag. S.	-59 58			-61 13				
			Direct.	-59 51			-61 06				
	-65 12	350 00	Direct.	-60 28	S.E. ½ E.	-0 43	-61 11	-61 18	-35	-61 53	
			Direct.	-60 20	S.E. by S.	-1 03	-61 23				
			Direct.	-60 11	S.S.E. ½ E.	-1 09	-61 20				
28.	-66 00	353 00	Direct.	-61 42	S.E. by S.	-1 04	-62 46	-62 27	-35	-63 02	Very unsteady.
			Needle N.	-61 44	S.E. y E.	-0 36	-62 20				
			Needle S.	-61 35			-62 11				
			Direct.	-62 12	E.S.E.	-0 21	-62 33				
			Mag. N.	-61 49			-62 10				
			Mag. N.S.	-62 04			-62 25				
			Mag. S.	-62 15			-62 36				
			Direct.	-62 29	E. by S.	-0 06	-62 35				
	-66 02	353 13	Direct.	-62 12	E.S.E.	-0 21	-62 33	-62 33	-35	-63 08	
			Direct.	-62 04	S.E. by E. ½ E.	-0 29	-62 33				
Mar. 1.	-66 54	351 15	Direct.	-61 48	S.W. by S.	-1 16	-63 04	-62 57	-35	-63 32	Motion slight; steering well.
			Needle N.	-61 38			-62 54				
			Needle S.	-61 41			-62 57				
			Mag. N.	-61 34			-62 50				
			Mag. N.S.	-61 37			-62 53				
			Mag. S.	-61 48			-63 00				
			Direct.	-61 54	S.W.	-1 07	-63 04	-63 02	-35	-63 37	
	-67 05	351 00	Direct.	-62 04			-63 11				
			Direct.	-62 07	S.W. by W.	-0 47	-62 54				
2.	-68 08	348 10	Direct.	-62 28	S.W.	-1 07	-63 35	-63 34	-35	-64 09	Steering well; table not very steady.
			Needle N.	-62 16			-63 23				
			Needle S.	-62 25			-63 32				
			Mag. N.	-62 34			-63 41				
			Mag. N.S.	-62 14			-63 21				
			Mag. S.	-62 35			-63 42				
			Direct.	-62 28			-63 35				
			Direct.	-62 54	S.W. by W.	-0 49	-63 43				
3.	-68 32	347 12	Direct.	-63 09	E.S.E.	-0 22	-63 31	-63 29	-35	-64 14	
			Direct.	-63 22	E. by S.	-0 06	-63 28				
4.	-69 24	345 30	Direct.	-62 56	S.W.	-1 09	-64 05	-64 49	-35	-65 24	Table very steady; steering well.
			Direct.	-63 52			-65 01				
			Needle N.	-63 37			-64 46				
			Needle S.	-63 45			-64 54				
			Mag. N.	-63 50			-64 59				
			Mag. N.S.	-63 43			-64 52				
			Mag. S.	-63 38			-64 47				
			Direct.	-63 56			-65 05				
			Direct.	-63 23	S.S.W.	-1 29	-64 52				
			Direct.	-63 28	S.W. by S.	-1 19	-64 47				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843.											
Mar. 5.	−71° 09′	344° 10′	Direct.	−65° 13′	S.E.	−0° 58′	−66° 11′	−66° 09′	−35′	−66° 44′	Table steady.
			Needle N.	−64 55			−65 53				
			Needle S.	−65 09			−66 07				
			Mag. N.	−65 10			−66 08				
			Mag. N.S.	−65 10			−66 08				
			Mag. S.	−65 16			−66 14				
			Direct.	−65 13			−66 11				
			Direct.	−65 22			−66 20				
6.	−71 08	344 18	Direct.	−66 01	E. by S.	−0 08	−66 09		−35	−66 44	
7.	−70 33	343 23	Direct.	−65 41	N. by E.	+1 25	−64 16		−35	−64 51	Very unsteady.
8.	−70 28	342 26	Direct.	−65 15	E.S.E.	−0 22	−65 37	−65 25	−35	−66 00	Ship rolling and pitching much.
			Needle N.	−64 49			−65 11				
			Needle S.	−64 57			−65 19				
			Direct.	−65 12			−65 34				
9.	−69 36	344 15	Direct.	−65 19	N.E. by N.	+1 19	−64 00		−35	−64 35	Steering pretty well.
10.	−68 07	346 13	Direct.	−63 54	N.E.	+1 10	−62 44	−62 39	−35	−63 14	Strong wind; heavy sea; unsteady.
			Needle N.	−63 44			−62 34				
			Needle S.	−63 46			−62 36				
			Mag. N.	−63 43			−62 33				
			Mag. N.S.	−63 52			−62 42				
			Mag. S.	−63 56			−62 46				
			Direct.	−63 50			−62 40				
11.	−65 57	346 40	Direct.	−63 02	N. by E. ½ E.	+1 18	−61 44	−61 32	−35	−62 07	Fresh breeze; head sea.
			Needle N.	−62 01			−60 43				
			Needle S.	−62 56			−61 38				
			Mag. N.	−62 51			−61 33				
			Direct.	−62 56	N. by E.	+1 18	−61 38				
			Mag. N.S.	−63 04			−61 46				
			Mag. S.	−63 01			−61 43				
			Direct.	−62 50			−61 32				
12.	−63 58	346 25	Direct.	−61 21	N.E. by N.	+1 12	−60 09	−59 49	−35	−60 24	Heavy sea; steering badly.
			Needle N.	−60 34			−59 22				
			Needle S.	−60 56			−59 44				
			Direct.	−61 15			−60 03				
13.	−61 35	349 00	Direct.	−59 32	N.E. by N.	+1 08	−58 24	−58 17	−35	−58 52	Heavy sea; steering wildly.
			Needle N.	−58 50			−57 42				
			Needle S.	−59 34			−58 26				
			Mag. N.	−59 29			−58 21				
			Mag. N.S.	−59 35			−58 27				
			Mag. S.	−59 24			−58 16				
			Direct.	−59 28			−58 20				
14.	−59 21	350 36	Direct.	−58 07	N.E. by N.	+1 08	−56 59	−56 54	−35	−57 29	Strong wind: steering wildly.
			Needle N.	−57 29			−56 21				
			Needle S.	−58 22			−57 14				
			Mag. N.	−58 11			−57 03				
			Mag. N.S.	−58 18			−57 10				
			Mag. S.	−57 47			−56 39				
			Direct.	−57 57			−56 49				
15.	−57 35	352 00	Direct.	−57 03	N.E. ½ N.	+1 01	−56 02	−55 51	−35	−56 26	Light breeze.
			Needle N.	−56 12			−55 11				
			Needle S.	−57 05			−56 04				
			Mag. N.	−57 02			−56 01				
			Mag. N.S.	−56 53			−55 52				
			Mag. S.	−56 50			−55 49				
			Direct.	−57 00			−55 59				
	−57 27	352 08	wt. 1 gr.	−56 45	N.E. ½ N.	+1 01	−55 44	−55 49	−35	−56 24	Steering well.
			wt. 1·5 gr.	−56 50			−55 49				
			wt. 2 grs.	−56 56			−55 55				
			wt. 2·5 grs.	−56 56			−55 55				
			Direct.	−56 45			−55 44				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Mar. 16.	−57° 09′	352° 44′	Direct.	−56° 37′	N.N.W. ½ W.	+0° 55′	−55° 42′	−55° 40′	−35′	−56° 15′	Table steady; steering well.
			Needle N.	−55 56			−55 01				
			Needle S.	−56 39			−55 44				
			Mag. N.	−56 37			−55 42				
			Mag. N.S.	−56 43			−55 48				
			Mag. S.	−56 26			−55 31				
			Direct.	−56 52	N.W. ½ W.	+0 40	−56 12				
17.	−56 44	353 45	Direct.	−56 38	N.N.W.	+0 58	−55 40	−55 29	−35	−56 04	Table steady.
			Needle N.	−55 52			−54 54				
			Needle S.	−56 38			−55 40				
			Direct.	−56 40			−55 42				
18.	−55 56	355 39	Direct.	−53 43	S.E. by S.	−0 50	−54 33	−54 33	−35	−55 08	Steering badly.
			Direct.	−55 27	N. by W.	+0 57	−54 30				
			Direct.	−55 36	N. by E.	+1 01	−54 35				
19.	−54 32	357 26	Direct.	−54 38	E. ½ N.	+0 19	−54 19	−54 15	−35	−54 50	Heavy head sea.
			Needle N.	−54 10			−53 51				
			Needle S.	−54 51			−54 32				
			Direct.	−54 37			−54 18				Steering well.
20.	−54 05	359 43	Direct.	−54 21	S.E. by E. ½ E.	−0 20	−54 41	−54 45	−35	−55 20	Steering well.
			Needle N.	−54 33			−54 53				
			Direct.	−54 29	E.S.E.	−0 13	−54 42				
			Needle N.	−54 29			−54 42				
			Needle S.	−54 33			−54 46				
	−54 07	359 58	Mag. N.	−54 51	E.S.E.	−0 13	−55 04	−54 56	−35	−55 31	Not very steady.
			Mag. N.S.	−54 38			−54 51				
			Mag. S.	−54 36			−54 49				
			Direct.	−54 44			−54 57				
			Direct.	−54 47			−55 00				
24.	−50 52	8 47	Direct.	−56 46	N.E. ½ N.	+1 00	−55 46	−55 29	−35	−56 04	Table steady; ship steering with difficulty.
			Needle N.	−56 01			−55 01				
			Needle S.	−56 25			−55 25				
			Mag. N.S.	−56 31			−55 31				
			Direct.	−56 43			−55 43				
	−50 19	9 15	Direct.	−56 18	N.E.	+0 58	−55 20	−55 19	−35	−55 54	
			Needle N.	−56 16			−55 18				
25.	−47 36	10 41	Direct.	−56 18	N.E.	+0 58	−55 20	−55 11	−35	−55 46	Table steady; each entry is a mean of many readings.
			Needle N.	−55 40			−54 42				
			Needle S.	−56 19			−55 21				
			Mag. N.S.	−56 11			−55 13				
			Direct.	−56 18			−55 20				
26.	−45 38	11 52	Direct.	−55 47	N.E.	+0 55	−54 52	−54 46	−35	−55 21	Table steady; each entry is a mean of many readings.
			Needle N.	−55 23			−54 28				
			Needle S.	−55 55			−55 00				
			Mag. N.	−55 40			−54 45				
			Mag. N.S.	−55 49			−54 54				
			Mag. S.	−55 30			−54 35				
			Direct.	−55 45			−54 50				
27.	−43 55	13 16	Direct.	−55 15	E.N.E.	+0 47	−54 28	−54 27	−35	−55 02	Table steady.
			Needle N.	−54 33			−53 46				
			Needle S.	−55 20			−54 33				
			Mag. N.	−55 14			−54 27				
			Mag. N.S.	−55 20			−54 33				
			Mag. S.	−55 41			−54 54				
			Direct.	−55 17			−54 30				
28.	−43 15	14 30	Direct.	−55 06	E.N.E.	+0 47	−54 19	−54 38	−35	−55 13	Very steady; steering well.
			Needle N.	−54 38			−53 51				
			Needle S.	−55 40			−54 53				
			Direct.	−55 16	N.E. by E.	+0 52	−54 24				
			wt. 1 gr.	−55 01			−54 09				

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. Mar. 28.	-43° 15′	14° 30′	wt. 1·5 gr.	-55° 28′			-54° 34′	-54° 38′	-35′	-55° 13′	Very steady; steering well.
			wt. 2 grs.	-55 55			-55 01				
			wt. 2·5 grs.	-56 29			-55 35				
			Direct.	-55 41			-54 47				
			Needle N.	-54 56	N.E. ½ E.	+0° 54′	-54 02				
			Needle S.	-55 55			-55 01				
			Mag. N.	-55 28			-54 34				
			Mag. N.S.	-55 43			-54 49				
			Mag. S.	-55 35			-54 41				
	-43 11	14 43	Direct.	-55 29	N.E. ½ E.	+0 54	-54 35		-35	-55 10	
29.	-41 58	15 11	Direct.	-55 05			-54 09				
			Needle N.	-55 49			-54 53				
			Needle S.	-55 31			-54 35				
			Mag. N.	-54 56	N.E.	+0 56	-54 00	-54 17	-35	-54 52	Slight motion; steering well.
			Mag. N.S.	-55 06			-54 10				
			Mag. S.	-54 59			-54 03				
			Direct.	-55 06			-54 10				
30.	-40 12	16 06	Direct.	-54 59			-54 03				
			Needle N.	-54 17			-53 21				
			Needle S.	-55 01			-54 05				
			Mag. N.	-55 04	N.E.	+0 56	-54 08	-53 58	-35	-54 33	Cross motion; not steering well.
			Mag. N.S.	-55 01			-54 05				
			Mag. S.	-55 02			-54 06				
	-40 03	16 10	Direct.	-54 57	N.E.	+0 56	-54 01	-53 59	-35	-54 34	
			Direct.	-54 53			-53 57				
31.	-38 00	16 45	Direct.	-54 28			-53 38				
			Needle N.	-53 47	N.E. by E.	+0 50	-52 57				
			Needle S.	-54 44			-53 54				
			Mag. N.	-54 11			-53 25	-53 29	-35	-54 04	Head sea; very unsteady.
			Mag. N.S.	-54 17			-53 31				
			Mag. S.	-54 16	E.N.E.	+0 46	-53 30				
			Direct.	-54 19			-53 33				
April 1.	-36 04	16 32	Direct.	-53 56			-53 10				
			Needle N.	-52 58			-52 12				
			Needle S.	-53 58			-53 12				
			Mag. N.	-53 51			-53 05				
			Mag. N.	-53 53	N.E. by E. ½ E.	+0 46	-53 07	-52 52	-35	-53 27	Head sea; pitching.
			Mag. S.	-53 00			-52 14				
			Direct.	-53 48			-53 02				
	-36 00	16 32	Direct.	-53 38			-52 52				
2.	-35 21	16 22	Direct.	-52 41	E.	+0 10	-52 31				
			Direct.	-52 29			-52 24				
			Needle N.	-51 36			-51 31				
			Needle S.	-52 59			-52 54				
			Mag. N.	-52 19			-52 14				
			Mag. N.S.	-52 34			-52 29				
			Mag. S.	-52 39			-52 34				
			Direct.	-52 46	E. ½ S.	+0 05	-52 41	-52 30	-35	-53 05	Little motion.
			wt. 0·5 gr.	-52 28			-52 23				
			wt. 1 gr.	-52 15			-52 10				
			wt. 1·5 gr.	-53 01			-52 56				
			wt. 2 grs.	-52 43			-52 38				
			wt. 2·5 grs.	-53 12			-53 07				
			Direct.	-52 37	E.	+0 10	-52 27				
3.	-35 03	17 06	Direct.	-52 18			-52 28				
			Direct.	-52 16			-52 26				
			wt. 0·5 gr.	-52 10			-52 20				
			wt. 1 gr.	-52 07			-52 17				
			wt. 1·5 gr.	-52 19	E.S.E.	-0 10	-52 29	-52 35	-35	-53 10	Table steady.

Observations of Inclination, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Observed Inclination. Face East.	Direction of ship's head.	Correction for Deviation.	Corrected Inclination.		Index Correction.	True Inclination.	Remarks.
1843. April 3.	−35° 03′	17° 06′	wt. 2 grs.	−52° 37′	E.S.E.	−0° 10′	−52° 47′	−52° 35′	− 35′	−53° 10′	Table steady.
			wt. 2·5 grs.	−53 03			−53 13				
			Direct.	−52 24			−52 34				
			Mag. N.S.	−52 21			−52 31				
			Mag. N.	−52 19			−52 29				
			Mag. S.	−52 16			−52 26				
			Direct.	−52 24			−52 34				
			Direct.	−53 00	E. by N. ¼ N.	+0 30	−52 30				
			Direct.	−53 02	W.N.W.	+0 20	−52 42				
			Direct.	−53 53	N.E. by E.	+0 49	−53 04				
6.	Simon's Bay, Cape of Good Hope.		Direct.	−52 49	On shore ...	......	−53 00		−35	−53 35	
	−34 11	18 26	Needle S.	−53 19							
			Mag. N.	−52 49							
			Mag. N.S.	−52 54							
			Mag. S.	−52 55							
			wt. 0·5 gr.	−52 55							
			wt. 1 gr.	−52 55							
			wt. 1·5 gr.	−53 24							
			wt. 2 grs.	−53 42							
			Direct.	−52 45							
			Direct.	−52 47							
			Direct.	−52 47							

Observations of the INTENSITY of the Magnetic FORCE made in Her Majesty's Ship 'Erebus' with Needle R. F. 5, and Deflector R. F. 4, between September 1842 at Port Louis, and April 1843 at Simon's Bay, Cape of Good Hope.

Observers Captain Sir JAMES CLARK ROSS and Lieut. ALEXANDER JOHN SMITH, R.N.

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.		Correction for Deviation.	Corrected Intensity.	Remarks.
1842.	° ′	° ′		° ′						
Sept. 8.	Running out of Harbour.		S.	71 38	E. ½ N.	9·75	9·79	+·03	9·82	
			N.	67 46	E. ½ N.	9·83				
9.	−53 03	302 05	S.	69 38	S.S.W.	10·10	10·07	−·15	9·92	Unsteady.
			N.	66 01		10·05				
13.	−54 03	305 26	S.	69 56	W.S.W.	10·03	9·96	−·04	9·92	Much motion.
			N.	66 51		9·90				
14.	−53 47	304 48	S.	69 16	S. by W.	10·17	10·08	−·15	9·93	A great deal of motion.
			N.	66 19		9·99				
15.	−54 43	304 30	N.	65 35	S.E.	10·12	10·12	−·10	10·02	Blowing hard, with much motion.
16.	−54 42	304 46	S.	69 35	W.S.W.	10·13	10·10	−·04	10·06	
			N.	65 48		10·08				
18.	−55 40	296 52	S.	66 02	S.W. ½ W.	10·82	10·83	−·10	10·73	
			N.	62 08		10·82				
			wt. 2 grs.	16 02		11·03				
			wt. 3 grs.	25 36		10·58				
			wt. 4 grs.	33 58		10·91				
19.	Standing towards St. Martin's Cove.		S.	65 04	W.N.W.	10·22	10·66	+·05	10·71	
			N.	60 53		11·10				
22.	St. Martin's Cove.		S.	64 32	Observed on shore.	11·17	11·13	......	11·13	Calm and clear.
	−55 51	292 28	N.	60 51		11·11				
			wt. 1 gr.	7 44		11·32				
			wt. 2 grs.	16 03		11·02				
			wt. 3 grs.	24 32		11·01				
			wt. 4 grs.	33 03		11·17				
			wt. 5 grs.	43 09		11·14				
			wt. 6 grs.	54 55		11·17				
Nov. 7.	Running out of St. Martin's Cove.		S.	63 21	S.E.	11·47	11·45	−·11	11·34	
			N.	59 30		11·44				
8.	−55 39	296 00	S.	66 10	N.E. by E.	10·81	10·76	+·11	10·87	
			N.	62 35		10·70				
11.	−54 24	300 08	S.	69 21	.	10·17	10·20	+·16	10·36	Moderate and fine.
			N.	65 11		10·20				
			wt. 2 grs.	17 21		10·22				
			wt. 3 grs.	27 00		10·07				
			wt. 4 grs.	36 08		10·34				
12.	−52 52	301 05	S.	70 28	N.	9·95	9·95	+·16	10·11	
			N.	66 35		9·94				
			wt. 2 grs.	17 47		9·98				
			wt. 3 grs.	27 35		9·87				
			wt. 4 grs.	37 33		10·00				
16.	−51 32	301 53	S.	71 18	Observed on shore.	9·82	9·90	......	9·90	Upper Dip House.
	Port Louis.		N.	67 05		9·85				
			wt. 1 gr.	8 29		10·33				
			wt. 2 grs.	18 22		9·67				
			wt. 3 grs.	27 07		10·03				
			wt. 4 grs.	38 01		9·90				
Sept. 22	St. Martin's Cove.		S.	64 34	Observed on shore. Face West	11·17	10·94	......	10·94	
	−55 51	292 28	N.	61 08		11·04				
			wt. 1 gr.	8 07		10·79				
			wt. 2 grs.	16 30		10·73				
			wt. 3 grs.	24 34		11·00				
			wt. 4 grs.	34 01		10·89				
			wt. 5 grs.	44 08		10·94				
			wt. 6 grs.	56 37		10·95				

Observations of the Magnetic Force, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.		Correction for Deviation.	Corrected Intensity.	Remarks.
1842. Nov. 16.	−51° 32′ Port	301° 53′ Louis.	wt. 5 grs.	49° 58′	Observed on shore.	9·95	9·90	……	9·90	Upper Dip House.
			wt. 6 grs.	69 25		9·77				
			S.	71 18		9·82				Lower Dip House.
			N.	66 58		9·86				
Dec. 13.	−51 32 Port	301 53 Louis.	S.	71 10	Observed on shore.	9·84	9·99	……	9·99	Upper Dip House.
			N.	66 54		9·86				
			wt. 1 gr.	8 18		10·56				
			wt. 2 grs.	17 27		10·16				
			wt. 3 grs.	28 13		9·67				
			wt. 4 grs.	37 38		9·98				
			wt. 5 grs.	49 10		10·07				
			wt. 6 grs.	69 17		9·77				
18.	−52 50	303 07	S.	69 33	S.E. by S.	10·15	10·14	−·13	10·01	
			N.	65 33		10·13				
19.	−54 23	303 59	S.	68 08	S.S.E.	10·39	10·40	−·15	10·25	Unsteady.
			N.	64 06		10·41				
20.	−55 51	305 18	S.	67 59	S.E. by S.	10·41	10·38	−·13	10·25	
			N.	64 25		10·35				
21.	−56 34	306 39	S.	68 01	S.S.E.	10·41	10·46	−·15	10·31	
			N.	63 35		10·52				
22.	−58 16	308 00	S.	66 34	S. by E. ½ E.	10·72	10·70	−·16	10·54	
			N.	62 41		10·68				
23.	−59 28	308 00	S.	65 21	S. by W.	10·96	11·01	−·18	10·83	
			N.	61 47		10·92				
			wt. 2 grs.	15 26		11·45				
			wt. 3 grs.	25 17		10·70				
24.	−61 23	307 41	N.	61 07	S. by W.	11·06	11·06	−·18	10·88	Very unsteady.
26.	−63 31	308 05	S.	65 27	N. by W.	10·95	10·97	+·16	11·13	Very steady.
			N.	61 24		10·98				
27.	−62 22	308 00	S.	64 03	S.W.	11·30	11·27	−·13	11·15	Very steady.
			N.	60 21		11·23				
			wt. 2 grs.	15 32	W.S.W.	11·38	11·23	−·07		
			wt. 3 grs.	24 09		11·17				
			wt. 4 grs.	32 20		11·40				
			wt. 5 grs.	43 08		11·15				
			wt. 6 grs.	55 41		11·07				
28.	−62 30	306 30	S.	63 37	S.W.	11·41	11·36	−·14	11·22	
			N.	60 01		11·31				
29.	−62 36	306 20	S.	64 16	N.N.E.	11·24	11·23	+·16	11·39	
			N.	60 22		11·23				
30.	−63 36	305 00	S.	63 20	E. by S.	11·47	11·40	·00	11·40	
			N.	59 50		11·34				
31.	−63 39	304 40	S.	62 46	S.S.E.	11·67	11·70	−·17	11·56	Perfectly steady.
			N.	59 03		11·56				
			wt. 2 grs.	14 41		12·02				
			wt. 3 grs.	23 17		11·57				
			wt. 4 grs.	30 59	S. by W.	11·84	11·80	−·20		
			wt. 5 grs.	40 11		11·81				
			wt. 6 grs.	51 10		11·74				
1843. Jan. 1.	−64 23	304 00	wt. 2 grs.	14 37	W. by S.	12·08	11·81	−·02	11·79	
			wt. 3 grs.	22 49		11·79				
			wt. 4 grs.	31 02		11·82				
			wt. 5 grs.	41 12		11·57				
Nov.	−51 32	301 54	S.	71 48	Observed on shore. Face West.	9·79	9·61	……	9·61	
			N.	67 41		9·76				
			wt. 1 gr.	9 28		9·26				
			wt. 2 grs.	18 53		9·42				
			wt. 3 grs.	28 41		9·52				
			wt. 4 grs.	39 27		9·59				
			wt. 5 grs.	50 54		9·82				
			wt. 6 grs.	70 06		9·72				

Observations of the Magnetic Force, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.		Correction for Deviation.	Corrected Intensity.	Remarks.
1843.										
Jan. 2.	−64° 26	303° 52′	S.	62° 16′	Observed on ice.	11·74	11·69	......	11·69	
			N.	58 43		11·64				
4.	−64 32	304 20	S.	63 01	N. by W. ½ W.	11·56	11·50	+·19	11·69	
			N.	59 34		11·43				
5	−64 18	308 39	S.	62 56	W. by N.	11·56	11·50	+·05	11·55	
			N.	59 25		11·44				
7.	−64 34	302 50	S.	62 13	W.N.W.	11·78	11·67	+·08	11·75	
			N.	59 04		14·56				
9.	−64 44	303 07	S.	62 30	N.W. ½ W.	11·68	11·62	+·12	11·74	
			N.	59 03		11·56				
	−64 44	303 07	S.	62 01	Observed on an ice-floe.	11·82	11·77	......	11·76	
			N.	58 29		11·72				
			wt. 2 grs.	14 28		12·19	11·76			
			wt. 3 grs.	23 21		11·53				
			wt. 4 grs.	31 41		11·61				
			wt. 5 grs.	40 54		11·64				
			wt. 6 grs.	50 36		11·83				
14.	−64 31	302 34	S.	62 27	W.	11·70	11·68	+·01	11·69	
			N.	58 42		11·66				
16.	−64 48	303 09	S.	62 39	N.N.W. ½ W.	11·66	11·87	+·16	12·03	
			N.	57 17		12·09				
			S.	62 06	Observed on an ice-floe.	11·79	11·71	......	11·71	
			N.	58 48		11·63				
19.	−64 22	305 01	S.	62 50	E.	11·64	11·57	−·01	11·56	
			N.	59 19		11·49				
20.	−64 18	304 18	S.	62 35	W.S.W.	11·67	11·62	−·07	11·55	
			N.	58 58		11·57				
22.	−64 12	303 50	S.	60 16	E.N.E.	12·32	11·88	+·09	11·97	
			N.	59 23		11·45				
29.	−64 05	304 00	S.	62 36	W.	11·67	11·59	+·01	11·60	
			N.	59 16		11·50				
Feb. 5.	−63 30	306 59	S.	63 52	N.E.	11·33	11·29	+·13	11·42	
			N.	60 16	N.E. ½ N.	11·24				
6.	−63 46	307 23	S.	63 43	N. ½ E.	11·36	11·28	+·18	11·46	
			N.	60 27		11·20				
8.	−63 49	308 53	S.	63 51	E. ½ S.	11·35	11·32	−·03	11·29	
			N.	60 02		11·30				
9.	−64 19	309 36	S.	63 05	E.S.E.	11·54	11·44	−·05	11·39	
			N.	59 47		11·37				
			wt. 2 grs.	15 42		11·27				
			wt. 3 grs.	23 03		11·66				
			wt. 4 grs.	32 00		11·51				
			wt. 5 grs.	42 31		11·28				
10.	−64 36	311 53	S.	64 08	N.E. by E.	11·27	11·24	+·12	11·36	
			N.	60 32		11·18				
11.	−64 37	314 21	S.	63 28	S.E. ½ S.	11·44	11·41	−·12	11·29	
			N.	59 48		11·37				
12.	−64 39	316 04	S.	64 43	N.E.	11·12	11·07	+·13	11·20	
			N.	61 17		11·01				
13.	−64 56	317 01	S.	63 59	S. by E.	11·30	11·26	−·18	11·08	
			N.	60 24		11·21				
14.	−65 06	318 46	S.	64 54	E.N.E.	11·08	10·99	+·09	11·08	
			N.	61 49		10·90				
15.	−64 40	320 12	S.	65 38	N.E. by N.	10·92	10·88	+·14	11·02	
			N.	62 01		10·85				
16.	−63 54	321 36	S.	66 41	N.E. by E. ½ E.	10·70	10·67	+·09	10·76	
			N.	62 59		10·63				
17.	−63 36	324 36	S.	68 10	N.N.E.	10·39	10·43	+·14	10·67	
			N.	63 53		10·46				

Observations of the Magnetic Force, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.		Correction for Deviation.	Corrected Intensity.	Remarks.
1843. Feb. 17.	−63° 36′	324° 36′	wt. 2 grs.	16° 26′	E.N.E.	10·78	10·63	+·08	10·71	
			wt. 3 grs.	25 25		10·66				
			wt. 4 grs.	35 20		10·55				
			wt. 5 grs.	46 08		10·58				
			wt. 6 grs.	59 56		10·55				
18.	−62 39	328 16	S.	69 31	N.E. by E.	10·13	10·18	+·10	10·31	
			N.	65 02		10·23				
			wt. 2 grs.	17 10	E.N.E.	10·33	10·25			
			wt. 3 grs.	26 55		10·11				
			wt. 4 grs.	36 15		10·32				
19.	−62 20	330 00	S.	69 46	N.E. by E. ½ E	10·09	10·12	+·09	10·21	
			N.	65 30		10·14				
20.	−61 59	333 43	S.	71 12	N.E.	9·84	9·88	+·12	10·00	
			N.	66 41		9·93				
21.	−61 37	336 05	S.	70 16	E. by S.	10·00	9·97	−·02	9·95	
			N.	66 39		9·93				
22.	−61 30	338 00	S.	71 40	E. by N.	9·77	9·78	+·04	9·82	
			N.	67 28		9·79				
23.	−61 46	341 02	S.	71 14	E.S.E.	9·83	9·84	−·04	9·80	
			N.	67 08		9·85				
24.	−62 36	344 08	S.	69 29	S.	10·19	10·17	−·17	10·00	
			N.	65 32		10·14				
25.	−63 58	345 10	S.	68 16	S. by E.	10·36	10·37	−·17	10·20	
			N.	64 14		10·38				
26.	−64 38	348 00	S.	68 13	S.E.	10·39	10·41	−·10	10·31	
			N.	64 01		10·43				
27.	−65 12	350 05	S.	68 09	S.E.	10·38	10·43	−·10	10·33	
			N.	63 50		10·47				
28.	−66 08	352 43	S.	67 13	S.E. by S.	10·57	10·59	−·13	10·46	
			N.	63 05		10·60				
Mar. 1.	−67 06	351 04	S.	65 55	S.W. ½ W.	10·86	10·79	−·11	10·68	
			N.	62 37		10·72				
2.	−68 14	347 40	S.	65 03	S.W.	11·05	11·04	−·13	10·91	
			N.	61 17		11·01				
			wt. 2 grs.	15 55		11·12				
			wt. 3 grs.	24 33		11·01				
			wt. 4 grs.	33 42		11·01				
3.	−68 32	347 09	S.	64 41	S.S.E.	11·14	11·11	−·15	10·96	
			N.	60 54		11·08				
4.	−69 26	345 31	S.	63 38	S.W. by S.	11·39	11·32	−·15	11·17	
			N.	60 13		11·25				
5.	−71 10	344 13	S.	62 34	S.E.	11·67	11·60	−·13	11·47	
			N.	59 07		11·53				
10.	−68 06	344 40	N.	62 03	N.E. by N.	10·84	10·84	+·17	11·01	
11.	−65 56	346 24	S.	67 42	N. by E.	10·48	10·51	+·16	10·67	
			N.	63 32		10·53				
12.	−64 31	346 01	N.	65 36	N.N.E.	10·12	10·12	+·14	10·26	Very unsteady.
13.	−61 34	348 39	S.	73 07	N.E. by N.	9·51	9·58	+·13	9·71	
			N.	68 21		9·65				
14.	−59 34	350 34	S.	75 54	N.E. by N.	9·09	9·16	+·13	9·29	
			N.	70 55		9·23				
15.	−57 27	352 08	S.	79 14	N.E. by N.	8·60	9·06	+·12	9·18	
			N.	73 00		8·93				
			wt. 2 grs.	18 46		9·48				
			wt. 3 grs.	29 49		9·20				
			wt. 4 grs.	42 09		9·09				
16.	−57 09	352 45	S.	80 12	N.W. ½ N.	8·48	8·67	+·11	8·78	
			N.	73 36		8·85				
17.	−56 38	353 57	S.	80 54	N.N.W.	8·37	8·52	+·14	8·66	
			N.	74 49		8·67				

Observations of the Magnetic Force, Her Majesty's Ship 'Erebus' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.		Correction for Deviation.	Corrected Intensity.	Remarks.
1843. Mar. 18.	−55° 38′	355° 32′	S.	81° 04′	E.NE.	8·36	8·54	+·08	8·62	
			N.	74 27		8·73				
20.	−34 07	359 56	S.	84 03	E.S.E.	8·00	8·22	−·04	8·28	Deflector R. F. 4.
			N.	76 38		8·43				
			S.	54 50		8·37	8·38	−·04	8·34	Deflector R. F. 3.
			N.	55 14		8·40				
24.	−50 37	9 03	S.	55 44	N.E.	8·26	8·17	+·12	8·29	
			N.	57 45		8·09				
25.	−47 38	10 51	S.	56 34	N.E.	8·10	8·03	+·12	8·15	
			N.	58 32		7·96				
26.	−45 32	11 54	S.	57 51	N.E.	7·86	7·84	+·12	7·96	
			N.	59 33		7·83				
27.	−43 57	13 16	S.	58 22	N.E. by E.	7·82	7·86	+·10	7·96	
			N.	59 57		7·78				
			wt. 2 grs.	22 21		8·02				
			wt. 3 grs.	35 32		7·87				
			wt. 4 grs.	51 11		7·83				
28.	−43 10	14 44	S.	58 08	N.E.	7·84	7·70	+·13	7·83	
			N.	60 07		7·75				
			wt. 2 grs.	23 26		7·67				
			wt. 3 grs.	36 05		7·77				
			wt. 4 grs.	54 31		7·49				
29.	−41 48	15 09	S.	58 42	N.E. ½ N.	7·75	7·72	+·13	7·85	
			N.	60 36		7·70				
30.	−40 15	15 47	S.	59 45	N.E.	7·60	7·58	+·13	7·71	
			N.	61 30		7·57				
31.	−37 40	16 40	S.	59 56	N.E. by E.	7·57	7·56	+·11	7·67	
			N.	61 41		7·56				
April 1.	−35 59	16 34	S.	60 32	N.E. by E.	7·49	7·48	+·11	7·59	
			N.	62 19		7·48				
2.	−35 26	16 22	S.	60 07	E.	7.55	7·51	+·02	7·53	
			N.	62 14		7·47				
4.	−35 00	17 00	S.	60 22	N.E. by E. ½ E.	7·52	7·46	+·10	7·56	
			N.	63 01		7·40				
6.	Block House Point, Simon's Bay.		S.	59 45	Observed on shore.	7·60	7·59	……	7·59	
			N.	61 43		7·56				
	−34 11	18 26	wt. 1 gr.	11 19·5		7·76				
			wt. 2 grs.	23 43·0		7·58				
			wt. 3 grs.	36 59·4		7·60				
			wt. 3·5 grs.	44 21		7·63				
			wt. 4 grs.	55 52		7·36				
19.	Swinging Ship for deviation.		S.	59 33	W.	7·63	7·59	+·02	7·65	
			S.	59 37	W.S.W.	7·63		−·03	7·60	
			S.	59 41	S.W.	7·62		−·13	7·49	
			S.	58 58	S.S..W.	7·71		−·17	7·54	
			S.	58 52	S.	7·74		−·18	7·56	
			S.	59 00	S.S.E.	7·71		−·16	7·55	
			S.	58 57	S.E.	7·72		−·10	7·62	
			S.	59 31	E.S.E.	7·63		−·03	7·60	
			S.	59 58	E.	7·56		+·02	7·58	
			S.	60 06	E.N.E.	7·54		+·10	7·64	
			S.	60 28	N.E.	7·49		+·13	7·62	
			S.	60 35	N.N.E.	7·48		+·15	7·63	
			S.	60 41	N.	7·49		+·15	7·64	
			S.	60 19	N.N.W.	7·52		+·14	7·66	
			S.	59 55	N.W.	7·55		+·11	7·66	
			S.	59 50	W.N.W.	7·56		+·06	7·62	
								Mean …	7·60	

Observations of the INTENSITY of the Magnetic FORCE made in Her Majesty's Ship 'Terror' with Needle F. C. B., between September 9, 1842, and April 20, 1843.

Observers Captain FRANCIS RAWDON CROZIER and Mr. THOMAS E. L. MOORE, Mate, R.N.

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1842.											
Sept. 9.	−52° 48′	303° 10′	N.	42° 50′	S.S.W.	10·54	10·44		−·15	10·29	Steering tolerably.
			S.	40 42		10·34					
16.	−54 42	305 30	N.	42 37	W.S.W.	10·63	10·39		−·04	10·35	Steering badly; very unsteady.
			S.	41 15		10·15					
18.	−55 30	297 00	N.	41 11	S.W.	11·18	11·15		−·11	11·04	Steady; steering well.
			S.	38 38		11·11					
Oct. 3.	St. Martin's Cove,		N.	40 47	Observed on	shore			......	11·19	
	Cape Horn.		S.	38 23							
	−55 51	292 28	wt. 1 gr.	15 04							
			wt. 1·5 gr.	22 41							
			wt. 2 grs.	30 35							
			wt. 2·5 grs.	39 28							
			wt. 3 grs.	48 57							
			wt. 3·5 grs.	61 10							
Nov. 7.	−56 02	292 57	N.	40 12	E.N.E.	11·59	11·32		+·08	11·40	Steering well; slight motion.
			S.	38 43		11·06					
8.	−55 52	295 41	N.	41 58	N.E. by E.	10·87	10·80		+·10	10·90	Much motion.
			S.	39 36		10·74					
11.	−55 05	299 49	N.	41 50	N.	11·01	10·75		+·16	10·91	Steering steady.
			S.	40 17		10·49					
12.	−52 26	301 16	N.	44 27	N.E. by E.	9·97	9·90		+·10	10·00	Steering well.
			S.	42 13		9·82					
16.	Port Louis.		N.	44 12	Observed on	shore			......	9·92	
	−51 32	301 53	S.	42 03							
			wt. 1 gr.	16 54							
			wt. 1·5 gr.	25 39							
			wt. 2 grs.	34 58							
			wt. 2·5 grs.	45 42							
			wt. 3 grs.	58 16							
Dec. 3.	Port Louis.		N.	44 31	Observed on	shore			......	9·91	
	−51 32	301 53	S.	42 01							
			wt. 1 gr.	17 07							
			wt. 1·5 gr.	25 36							
			wt. 2 grs.	34 54							
			wt. 2·5 grs.	45 45							
			wt. 3 grs.	57 58							
17.	Running out of		wt. 1 gr.	17 11	E.		9·88	9·89	·00	9·89	Steady; steering well.
	Berkeley Sound.		wt. 1·5 gr.	25 49							
			wt. 2 grs.	35 13							
			wt. 2·5 grs.	45 03							
			wt. 3 grs.	58 21							
			N.	44 25	E.	9·98	9·90				
			S.	42 12		9·82					
18.	−52 46	303 18	N.	43 40	S.E. by S.	10·24	10·15	10·15	−·12	10·03	Steering badly, Table unsteady.
			S.	41 06		10·05					
			wt. 1 gr.	16 13			10·16				
			wt. 1·5 gr.	24 28							
			wt. 2 grs.	34 20							
			wt. 2·5 grs.	44 17							
			wt. 3 grs.	58 52							
19.	−53 38	303 43	N.	43 26	S. by E.	10·32	10·28		−·16	10·12	Very unsteady.
			S.	40 57		10·25					
20.	−55 26	305 20	N.	42 18	S.S.E.	10·74	10·53		−·15	10·38	Steering well.
			S.	40 44		10·32					

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1842. Dec. 20.	−55° 57′	305° 27′	wt. 1 gr.	15° 29′	S.E. by S.		10·54		−·12	10·42	Table steady.
			wt. 1·5 gr.	23 51							
			wt. 2 grs.	33 33							
			wt. 2·5 grs.	42 54							
			wt. 3 grs.	53 06							
	−56 00	305 30	N.	42 19	S.E. by S.	10·74	10·63		−·12	10·51	Table steady.
			S.	40 09		10·53					
21.	−56 55	306 40	N.	42 36	S.S.E.	10·64	10·58	10·66	−·15	10·51	Unsteady; steering badly.
			S.	40 11		10·53					
			wt. 1 gr.	14 47			10·70				
			wt. 1·5 gr.	24 23							
			wt. 2 grs.	32 13							
			wt. 2·5 grs.	42 01							
22.	−57 50	307 58	N.	41 26	S.S.E.	11·08	11·01		−·15	10·86	Much motion; steering badly.
			S.	39 05		10·94					
	−58 25	307 53	wt. 1 gr.	14 48	S. by E.		10·90	10·91	−·17	10·74	
			wt. 1·5 gr.	23 06							
			wt. 2 grs.	32 05							
			wt. 2·5 grs.	41 19							
			wt. 3 grs.	51 04	S. by E. ½ E.						
			N.	41 52	S. by E.	10·90	10·95				
			S.	38 55		10·99					
23.	−59 57	307 53	N.	41 02	S. by W.	11·25	11·11		−·18	10·93	
			S.	38 58		10·97					
24.	−61 20	307 42	N.	40 53	S. by W.	11·32	11·34		−·18	11·16	
			S.	38 00		11·37					
25.	−62 12	307 47	N.	39 48	S.S.E.	11·21	11·32		−·15	11·17	Unsteady.
			S.	37 51		11·43					
26.	−62 25	307 58	N.	40 42	N.N.W.	11·38	11·20	11·06	+·15	11·21	Table steady; steering badly.
			S.	38 52		11·01					
			wt. 1 gr.	15 15	N.N.W. ½ W.	11·01	11·01				
			wt. 1·5 gr.	23 31							
			wt. 2 grs.	31 09							
			wt. 2·5 grs.	39 30							
			wt. 3 grs.	49 41							
27.	−62 18	308 17	N.	40 54	W. by S.	11·32	11·26	11·30	−·02	11·28	Steady.
			S.	38 29		11·20					
			wt. 1 gr.	14 16		11·32	11·32				
			wt. 1·5 gr.	21 55							
			wt. 2 grs.	30 48							
			wt. 2·5 grs.	39 35							
			wt. 3 grs.	49 09							
28.	−62 30	306 52	N.	40 33	S.W.	11·44	11·35		−·14	11·21	
			S.	38 12		11·26					
	−62 42	305 27	N.	40 01	S.W.	11·66	11·58	11·65	−·14	11·51	
			S.	37 40		11·51					
			wt. 1 gr.	13 56			11·68				
			wt. 1·5 gr.	21 13							
			wt. 2 grs.	29 53							
			wt. 2·5 grs.	37 38							
29.	−63 35	305 47	N.	39 26	S.W. by W.	11·91	11·80		−·10	11·70	Slight motion.
			S.	37 14		11·69					
31.	−63 57	304 32	N.	39 38	S.	11·84	11·83	11·89	−·20	11·69	Very steady.
			S.	36 56		11·82					
			wt. 1 gr.	13 46			11·91				
			wt. 1·5 gr.	20 20							
			wt. 2 grs.	29 08							
			wt. 2·5 grs.	37 22							
			wt. 3 grs.	45 57							

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1843. Jan. 2.	−64° 27′	303° 54′	N.	38° 53′	On ice.	12·16	11·97	11·79	……	11·79	600 yards from the ship.
			S.	37 01		11·78					
			wt. 1 gr.	14 03		11·73	11·72				
			wt. 1·5 gr.	21 31		11·65					
			wt. 2 grs.	29 15		11·66					
			wt. 2·5 grs.	37 20		11·74					
			wt. 3 grs.	46 11		11·84					
3.	−64 30	304 10	N.	40 08	N.W. ½ W.	11·62	11·64		+·12	11·76	
			S.	37 20		11·65					
4.	−64 38	304 20	N.	40 37	N.W.byW.½W.	11·42	11·49		+·08	11·70	Sailing amongst loose ice.
			S.	37 34		11·56					
			wt. 1 gr.	14 26	N. by E.		11·58		+·16		
			wt. 1·5 gr.	21 58							
			wt. 2 grs.	29 52							
			wt. 2·5 grs.	37 37							
			wt. 3 grs.	46 51	N.N.E. ½ E.						
			wt. 3·5 grs.	58 15	N.N.E.						
5.	−64 13	304 06	N.	39 31	W.	11·90	11·77		+·02	11·79	
			S.	37 19		11·65					
			wt. 1 gr.	14 18	E. by N.	11·53	11·60		+·17	11·77	Sailing amongst loose ice.
			wt. 1·5 gr.	21 52	N.E. ½ N.	11·47					
			wt. 2 grs.	29 35	N.	11·54					
			wt. 2·5 grs.	37 30		11·70					
			wt. 3 grs.	47 16		11·63					
			wt. 3·5 grs.	58 24		11·70					
6.	−64 12	303 04	N.	39 06	W.	12·06	11·87		+·01	11·88	
			S.	37 16		11·68					
7.	−64 28	303 20	N.	39 17	S. ½ W.	11·98	11·98		−·17	11·87	
			S.	36 33		11·99					
			wt. 1 gr.	14 01	W.N.W.	11·76	11·76		+·06		
			wt. 1·5 gr.	20 36	S. ½ W.	12·14	12·07		−·17		
			wt. 2 grs.	28 20		12·00					
			wt. 2·5 grs.	36 27		11·98					
			wt. 3 grs.	44 51		12·11					
			wt. 3·5 grs.	55 12		12·14					
9.	−64 41	302 52	N.	39 24	S.E. by E.	11·94	11·95	11·88	−·06	11·82	
			S.	36 37		11·95					
			wt. 1 gr.	14 06	E.S.E.	11·69	11·82				
			wt. 1·5 gr.	21 19		11·75					
			wt. 2 grs.	28 33		11·92					
			wt. 2·5 grs.	36 38		11·93					
			wt. 3 grs.	45 40		11·94	11·94				
			wt. 3·5 grs.	56 31		11·95					
	−64 48	303 09	N.	39 27	Observed on ice.	11·90	11·86	11·85	……	11·85	800 yards from the ship.
			S.	36 57		11·82					
			wt. 1 gr.	13 34		12·14	11·85				
			wt. 1·5 gr.	21 23		11·72					
			wt. 2 grs.	29 42		11·50					
			wt. 2·5 grs.	36 59		11·83					
			wt. 3 grs.	45 49		11·91					
			wt. 3·5 grs.	56 16		11·99					
10.	−64 38	302 40	N.	39 07	S.W. by S.	12·06	11·97		−·16	11·81	
			S.	36 45		11·88					
12.	−64 40	302 07	N.	39 34	W.N.W.	11·88	11·72		+·07	11·79	Sailing amongst loose ice; very steady.
			S.	37 35		11·56					
16.	−64 30	303 04	N.	39 47	N.N.W.	12·00	11·78		+·14	11·92	Fast to a floe.
			S.	37 32		11·56					

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1843. Jan. 18.	−64° 04′	305° 00′	N.	39° 56′	N.E. by E.	11·71	11·63	11·53	+·13	11·66	Sailing amongst loose ice.
			S.	37 31		11·56					
			wt. 1 gr.	14 19	N.E. ½ E.		11·50				
			wt. 1·5 gr.	22 09							
			wt. 2 grs.	29 50							
			wt. 2·5 grs.	38 00							
			wt. 3 grs.	47 19							
			wt. 3·5 grs.	58 45							
20.	−64 16	304 42	N.	39 41	W. by S. ½ S.	11·81			−·05	11·76	
21.	−64 20	304 40	N.	39 33	E.S.E.	11·86	11·82		−·06	11·76	
			S.	37 01		11·78					
22.	−64 12	304 07	wt. 1 gr.	13 59	E.N.E.		11·63		+·10	11·74	
			wt. 1·5 gr.	21 28							
			wt. 2 grs.	29 56							
			wt. 2·5 grs.	37 52	N.W.		11·63		+·11		
			wt. 3 grs.	47 42							
			wt. 3·5 grs.	58 05							
24.	−64 08	304 00	N.	39 31	N. ½ E.	11·88	11·68		+·16	11·84	
			S.	37 43		11·48					
26.	−64 04	304 10	N.	39 27	S.E.	11·91	11·85		−·13	11·72	
			S.	37 01		11·78					
28.	−64 02	304 15	N.	39 28	S.W.	11·90	11·83		−·15	11·68	
			S.	37 04		11·76					
Feb. 1.	−63 56	305 22	N.	39 54	W. ½ S.	11·68	11·63		−·02	11·61	
			S.	37 28		11·59					
2.	−64 24	305 30	wt. 1 gr.	14 16	W. by S.	11·63			−·03	11·60	
			wt. 1·5 gr.	21 46							
			wt. 2 grs.	29 33							
			wt. 2·5 grs.	37 40							
			wt. 3 grs.	46 41							
			wt. 3·5 grs.	57 57							
4.	−64 16	304 47	N.	40 04	E.N.E.	11·66	11·61		+·10	11·61	Steady.
			S.	37 31		11·57					
			N.	39 59	S. by E.	11·67	11·68		−·17		Sailing amongst loose ice.
			S.	37 14		11·69					
7.	−63 47	308 00	N.	40 02	S.E. by E.	11·66	11·63		−·13	11·50	Sailing amongst loose ice.
			S.	37 24	S.E. by S.	11·61					
8.	−63 42	308 45	N.	40 40	N. ½ E.	11·39	11·30		+·19	11·49	Unsteady.
			S.	38 23		11·21					
9.	−64 19	309 40	wt. 1 gr.	14 35	E. by S.		11·48	11·47	−·04	11·43	
			wt. 1·5 gr.	21 49							
			wt. 2 grs.	29 57							
			wt. 2·5 grs.	38 22							
			wt. 3 grs.	47 50							
			wt. 3·5 grs.	59 08							
			N.	40 18		11·54	11·46				
			S.	37 59		11·37					
10.	−64 43	312 06	N.	40 46	E.N.E.	11·35	11·32		+·09	11·41	
			S.	38 13		11·29					
11.	−64 38	314 01	N.	40 50	N.	11·32	11·24		+·18	11·42	
			S.	38 33		11·15					
12.	−64 49	315 07	N.	40 54	E.N.E.	11·30	11·21		+·10	11·31	
			S.	38 38		11·11					
13.	−64 47	316 57	N.	41 00	S. by E. ½ E.	11·26	11·34		−·17	11·17	
			S.	37 50		11·42					

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1843.											
Feb. 14.	−64° 58′	318° 26′	wt. 1 gr.	14° 47′	E.		11·26	11·27	−·01	11·26	Little motion; steering well.
			wt. 1·5 gr.	22 20							
			wt. 2 grs.	30 41							
			wt. 2·5 grs.	38 59							
			wt. 3 grs.	49 09							
			wt. 3·5 grs.	61 05							
			N.	40 43		11·36	11·31				
			S.	38 15		11·26					
15.	−64 37	320 28	N.	41 24	N.E.	11·14	10·99		+·12	11·11	Steering badly.
			S.	39 19		10·84					
16.	−64 02	321 55	N.	41 08	N.E. by E.	11·21	11·19		+·11	11·30	Unsteady.
			S.	38 29		11·16					
17.	−63 59	324 18	N.	42 02	E.	10·85	10·81		−·01	10·80	Little motion.
			S.	39 31		10·77					
18.	−62 37	328 17	N.	43 09	E.N.E.	10·43	10·33		+·08	10·41	Little motion.
			S.	41 00		10·23					
19.	−62 13	330 28	wt. 1 gr.	16 30	E.		10·24	10·29	−·01	10·28	
			wt. 1·5 gr.	24 31							
			wt. 2 grs.	33 46							
			wt. 2·5 grs.	43 08							
			N.	43 10		10·44	10·40				
			S.	40 39		10·36					
20.	−62 05	333 38	N.	43 54	N. by E.	10·16	10·09		+·15	10·24	
			S.	41 31		10·03					
21.	−61 32	336 10	N.	43 53	E.	10·17	10·28		−·01	10·27	
			S.	40 36		10·38					
22.	−61 28	337 42	N.	43 52	S.W. ½ W.	10·16	10·18		−·11	10·06	Slight motion.
			S.	41 08		10·19					
			wt. 1 gr.	16 40	E.S.E.	9·98			−·03		
			wt. 1·5 gr.	25 38							
			wt. 2 grs.	34 20							
			wt. 2·5 grs.	44 15	S.E. by E.	10·24			−·07		
			wt. 3 grs.	56 33							
			wt. 3·5 grs.	75 39							
24.	−62 41	343 18	N.	43 06	S. ½ E.	10·40			−·16	10·13	Slight motion.
			S.	40 48							
			wt. 1 gr.	16 29	S. ½ E.	10·25					
			wt. 1·5 gr.	24 30							
			wt. 2 grs.	33 16							
			wt. 2·5 grs.	43 42							
			wt. 3 grs.	56 30							
25.	−64 14	345 30	N.	43 14	E.N.E.	10·41	10·34		+·08	10·42	Very unsteady.
			S.	40 55		10·27					
26.	−64 33	347 52	N.	42 28	S.E.	10·74	10·71		−·11	10·60	
			S.	39 45		10·69					
27.	−65 00	349 30	N.	41 57	S.S.E.	10·88	10·73		−·15	10·58	Much motion; very unsteady.
			S.	39 59		10·59					
28.	−66 00	353 00	N.	41 01	S.E. by E.	11·25	10·94		−·07	10·87	
			S.	39 53	E.S.E.	10·63					
Mar. 1.	−66 54	351 15	N.	40 42	S.W. by S.	11·38	11·15		−·15	11·00	Steering very well.
			S.	39 08		10·91					
2.	−68 08	348 10	N.	39 59	S.W.	11·67	11·45		−·15	11·30	Table unsteady.
			S.	38 27		11·23					
4.	−69 24	345 30	N.	39 36	S.W.	11·84	11·59		−·15	11·44	Table very steady.
			S.	38 04		11·34					
5.	−71 09	344 10	N.	38 52	S.W.	12·12	11·87		−·16	11·71	Steering well.
			S.	37 22		11·63					

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.			Correction for Deviation.	Corrected Intensity.	Remarks.
1843. Mar. 8.	−70° 28′	342° 26′	N.	39° 27′	E.S.E.	11·90	11·74		−·04	11·70	Short sea.
			S.	37 30		11·58					
10.	−68 07	346 23	N.	41 15	N.E.	11·15	11·04		+·15	11·19	Pretty steady.
			S.	39 05		10·94					
11.	−65 57	346 40	N.	42 21	N. by E. ½ E.	10·73	10·57		+·16	10·73	
			S.	40 30		10·41					
12.	−63 58	346 25	N.	43 32	N.E. by N.	10·30	10·18		+·13	10·31	
			S.	41 32		10·05					
13.	−61 35	349 00	N.	44 38	N.E. by N.	9·90	9·76		+·13	9·89	Heavy sea; steering wildly.
			S.	42 50		9·62					
14.	−59 21	350 36	N.	45 49	N.E. by N.	9·51	9·49		+·13	9·62	Smooth water; table steady.
			S.	43 18		9·47					
15.	−57 35	352 00	N.	46 35	N.E. ½ N.	9·27	9·12	8·96	+·12	9·08	Steering well; table steady.
			S.	45 01		8·96					
	−57 27	352 08	wt. 1 gr.	19 01	N.E. ½ N.		8·88				
			wt. 1·5 gr.	29 48							
			wt. 2 grs.	39 15							
			wt. 2·5 grs.	50 48							
16.	−57 09	352 44	N.	46 10	N.N.W. ½ W.	9·42	9·23		+·12	9·35	Smooth water; steering steady.
			S.	44 41		9·05					
17.	−56 44	353 45	N.	47 30	N.N.W.	8·99	8·97		+·13	9·10	
			S.	45 04		8·95					
19.	−54 32	357 26	N.	48 26	E. ½ N.	8·71	8·67		+·03	8·70	Table very unsteady.
			S.	46 09		8·64					
20.	−54 05	359 33	N.	47 29	S.E. by E. ½ E.		8·99	8·8$_2$	−·05	8·77	Steering well; table unsteady.
			N.	47 25	E.S.E.	9·02	8·73				
			S.	46 53		8·43					
24.	−50 52	8 47	N.	49 34	N.E. ½ N.	8·39	8·33		+·12	8·45	Table unsteady.
			S.	47 29		8·27					
	−50 19	9 15	N.	49 29	N.E.	8·41			+·11	8·52	
25.	−47 36	10 41	N.	50 01	N.E.	8·27	8·24		+·11	8·35	Table steady.
			S.	47 44		8·21					
26.	−45 38	11 52	N.	50 37	N.E.	8·10	8·03		+·11	8·14	Much difficulty in keeping the ship's head in one direction.
			S.	48 40		7·97					
27.	−43 55	13 16	N.	51 40	E.N.E.	7·82	7·86		+·10	7·96	Table steady.
			S.	48 59		7·89					
28.	−43 15	14 30	N.	51 12	E.N.E.	7·95	7·89	7·85	+·11	7·96	Very steady.
			S.	49 17		7·82					
			N.	51 29	N.E. ½ E.	7·88	7·82				
			S.	49 30		7·77					
	−43 11	14 43	wt. 1 gr.	21 33	N.E. ½ E.	7·87			+·12	7·99	
			wt. 1·5 gr.	33 14							
			wt. 2 grs.	45 21							
			wt. 2·5 grs.	63 40							
29.	−41 58	15 11	N.	51 21	N.E.	7·92	7·81		+·13	7·94	Table steady.
			S.	49 43		7·71					
30.	−40 12	16 06	N.	52 04	N.E.	7·73	7·69		+·13	7·82	Unsteady.
			S.	49 59		7·65					
31.	−38 00	16 45	N.	52 04	N.E. by E.	7·73	7·65		+·11	7·76	Head sea; unsteady.
			S.	50 17		7·58					
April 1.	−36 04	16 32	N.	52 30	N.E. by E. ½ E.	7·62	7·53		+·11	7·64	Quick motion.
			S.	50 50		7·45					
2.	−35 21	16 22	N.	52 43	E. ½ S.	7·56	7·52	7·55	+·01	7·56	Table steady.
			S.	50 46		7·47					
			wt. 1 gr.	22 42			7·56				
			wt. 1·5 gr.	34 29							
			wt. 2 grs.	48 30							
			wt. 2·5 grs.	67 17							

Observations of the Magnetic Force, Her Majesty's Ship 'Terror' (continued).

Date.	Lat.	Long.	Method employed.	Angle of Deflection. Face East.	Direction of ship's head.	Intensity.	Correction for Deviation.	Corrected Intensity.	Remarks.
1843. April 3	−35° 03′	17° 06′	wt. 1 gr.	21° 31′	E.S.E.	7·66	−·03	7·63	Table steady.
			wt. 1·5 gr.	34 06					
			wt. 2 grs.	48 06					
			wt. 2·5 grs.	68 18					
6.	Simon's Bay, Cape of Good Hope.		N.	52 36	Observed on shore.	7·60 } 7·60			
			S.	50 14		7·59			
	−34 11	18 26	wt. 0·5 gr.	11 22		7·56	......	7·56	
			wt. 1 gr.	22 21					
			wt. 1·5 gr.	34 09		7·54			
			wt. 2 grs.	48 19					
			wt. 2·5 grs.	66 41					
20.	On board for the corrections of the Deviation.		N.	52 41	W.	7·58	+·02	7·60	
			N.	53 31	W.N.W.	7·37	+·06	7·43	
			N.	53 12	N.W.	7·45	+·11	7·56	
			N.	53 12	N.N.W.	7·45	+·14	7·59	
			N.	53 14	N.	7·44	+·15	7·59	
			N.	53 29	N.N.E.	7·38	+·15	7·53	
			N.	53 20	N.E.	7·41	+·13	7·54	
			N.	53 05	E.N.E.	7·48	+·10	7·58	
			N.	52 43	E.	7·56	+·02	7·58	
			N.	52 32	E.S.E.	7·61	−·03	7·58	
			N.	52 06	S.E.	7·72	−·10	7·62	
			N.	51 47	S.S.E.	7·80	−·16	7·64	
			N.	51 49	S.	7·79	−·18	7·61	
			N.	52 04	S.S.W.	7·73	−·16	7·56	
			N.	52 06	S.W.	7·72	−·13	7·59	
			N.	52 15	W.S.W.	7·68	−·03	7·65	
					Mean	7·57	......	7·58	

XXI. *On the Anatomy and Physiology of the Nematoids, Parasitic and Free; with observations on their Zoological Position and Affinities to the Echinoderms.* By H. Charlton Bastian, *M.A., M.B. Lond., F.L.S.*

Received June 13,—Read June 15, 1865.

CONTENTS.

	Page
Introductory Remarks	545
Tegumentary Organs and Appendages	547
Muscular System	559
Nervous System	565
Organs of Sense	572
Organs of Digestion	573
Glandular System	581
Organs of Circulation—'Water-vascular System,' &c.	584
The function of Respiration—how performed?	602
Organs of Generation	604
Development and life-history	606
Powers of repair and tenacity of life	611
Zoological Position and Affinities	620

Although the parasitic Nematoids have been so long known and frequently submitted to anatomical examination, it is somewhat surprising that, even up to within quite a recent period, nothing was certainly known with regard to the arrangement in them of the nervous system, or as to whether they possessed any modification of the organs of circulation. The existence of both these systems has been asserted and denied over and over again by successive observers, and conflicting statements in this particular field of research have been so rife, that a well-known writer*, recently alluding to this subject, even goes so far as to state that the many discrepancies in the accounts given by leading Helminthologists of Nematoid anatomy "tend to throw great doubt upon the general value of histological observations among the Helminths." Although far from sharing in this opinion, I must admit that the tangled network of opposing statements is sufficiently disheartening.

As a necessary consequence of our deficient knowledge of the real anatomy of these animals, this order *Nematoidea* has been a continual stumbling-block in the path of the philosophic zoologist. What is their place in the animal kingdom? A question, surely, impossible to answer whilst so many doubts hung over the question of the arrangement of their nervous and circulatory organs; and it seems to me that many of the erroneous opinions which have been held concerning these parts may be traced to the influence of somewhat hasty and superficial views regarding the affinities of these animals, leavened too powerfully by a consideration of their mere worm-like external form. Moreover, the confusion has been heightened by the presence in the Nematoids of rather anomalous structures—the so-called "lateral and median lines"—which, though themselves neither vessels nor nerves, have, each in turn, been taken for both by different observers. The intimate connexion and blending of the real nervous system with these bodies in one part of their length, and its limited extent, account in a measure for its having so long escaped detection, since this system cannot possibly be properly examined without most careful dissection and after-preparation of the specimen.

---

* Dr. Cobbold, 'Entozoa: an Introduction to the Study of Helminthology,' 1864, p. 363.

Having become accidentally interested in the anatomy of the Nematoids, and having then been made fully aware of the unsatisfactory state of our knowledge concerning them, I felt a strong desire to be able to remove some of the existing difficulties, so as to place the subject upon a somewhat firmer foundation, and to discover what were the real affinities of these animals. In addition to the present memoir, this desire has resulted in the discovery and description* of 100 new species of free Nematoids, partly marine and partly freshwater; and my researches on this branch of the subject have convinced me that these may be considered to constitute one of the most numerous and widely distributed families in the whole animal kingdom, yielding in this respect, perhaps, only to the ubiquitous Diatomaceæ in the vegetable world. Their bodies are so transparent, and enticing for microscopical examination, that I was tempted on and on, far beyond the limits I had originally intended, in the hopes of being able to learn something from them concerning the moot points in Nematoid anatomy. But although many interesting facts have been thus acquired, still more have been gathered from my later investigations into the structure of the parasitic Nematoids—though, fortunately, the two sets of observations mutually throw light on one another.

The recognition of the great numerical abundance and wide distribution of these free Nematoids tends to throw much additional interest over the order *Nematoidea*, and make the Nematoids as a group quite unique among other animals; for in them we see a great assemblage, one division of which has long been known to constitute a section of the class Entozoa, most remarkable for the number of its representatives and the frequency with which they are met in the most varied organs of animals belonging to every grade from the Acalephæ upwards; whilst the other is now, also, known to be composed of animals, in all probability infinitely more numerous still, leading a free and independent life in all stages of their existence, tenanting almost every variety of natural external habitat where moisture exists, and even invading in some cases, as parasites, representatives of the vegetable kingdom. Yet, strange to say, the organization of these latter animals, as a whole, differs in no very obvious or important manner from that of their parasitic kindred. In accordance with their requirements, the sense-organs in many of the free Nematoids become more numerous, and other modifications obtain; still, so far as we have yet been able to ascertain, their essential structure is not materially modified, and the nature of the alterations encountered tends only to ally them more closely by organization as well as habitat to the members of the class Echinodermata.

---

* Monograph on the Anguillulidæ or Free Nematoids, Trans. of Linn. Soc. vol. xxv. p. 72.

The remarkable tenacity of life, and power of resuming all their vital manifestations after the most prolonged period of desiccation and torpidity, possessed by some of the free Nematoids, in common with the *Rotifera*, make them objects of extreme interest to the biologist, which interest, certainly, suffers no diminution from the fact that, so far as I have observed, this extraordinary attribute is possessed only by members of the four land and freshwater genera, *Tylenchus*, *Aphelenchus*, *Plectus*, and *Cephalobus*, whilst other representatives of the family are frail, and unable to recover even after the shortest periods of desiccation.

My observations on the anatomy of the parasitic Nematoids have been conducted more or less fully upon twenty-six species, some of which belong to each of the seven sections into which DUJARDIN* divided the order, though I have studied most completely seven species of the genus *Ascaris*, and of these especially *Ascaris lumbricoides* and *A. megalocephala.* In many important particulars these observations are in accordance with the results of the recent researches of Drs. SCHNEIDER and EBERTH in Germany, whose investigations have done so much to improve the state of our knowledge concerning the organization of these animals; though, as will be seen under the various subdivisions, there are many other points upon which I have been unable to reconcile my observations with those of either one or both of these anatomists. Although, therefore, difficulties and some disagreements still remain, yet I hope to be able to remove many which have hitherto obscured this subject, and to offer suggestions which, if accepted, will go far to solve the question of the zoological affinities of the Nematoids.

TEGUMENTARY ORGANS AND APPENDAGES.

Many misconceptions have prevailed concerning the nature of the integument in the Nematoids, as I have already pointed out in the paper "On the Structure and Nature of the *Dracunculus*"†. It has been described by Von SIEBOLD‡, DUJARDIN§, OWEN‖, and most other anatomists, as divisible into two main portions—a structureless epidermis composed of chitine, and a corium made up of layers of longitudinal and oblique decussating fibres. And, although in this communication I pointed out the fact that these so-called fibrous layers, or membranes, were not such in reality, but that, in common with the external more homogeneous layer, they were essentially epidermic in nature, consisting of chitinous lamellæ presenting various kinds of markings, and, in all probability, were excreted from some deep cellular layer, still, I had not at that time been able actually to recognize the existence of such a layer in the Nematoids. Since then I have fully satisfied myself of the existence of a distinct, deep, cellulo-granular layer from which the chitinous lamellæ are excreted, and which corresponds most likely with what Dr. COBBOLD describes as a 'homogeneous' granular layer*.

---

* Histoire Naturelle des Helminthes, 1845, p. 2.

† Trans. of Linn. Soc. vol. xxiv. p. 108.

‡ Manuel d'Anat. Comp. Trad. Française, 1850, p. 115.

§ Hist. Nat. des Helminthes, 1845.

‖ Lect. on Comp. Anat. 2nd edit. 1855, p. 99.

As a result of my recent investigations I can now make the following statements. The integument of all the Nematoids examined appeared to be composed essentially of two portions, an external, or 'ecderon,' varying much in different genera, though composed essentially of an uncertain number of layers of a colourless chitinous material, the outermost of which often presented markings, regular or irregular, on its surface; and an 'enderon,' or internal, active, formative portion, consisting of a cellular layer bounded on both sides by a loose fibrous membrane, uniting it externally with the epidermic layers, and internally with the muscles. In the intermuscular intervals, and especially in the lateral, this layer is much thickened, and projects between the muscles into the general cavity of the body so as to constitute the well-known, though much misunderstood, 'lateral and median lines' (Plate XXIII. fig. 1), concerning the nature of which so many conflicting statements have been made. The median lines are by no means so common as they seem to have been considered; in many Nematoids no traces of them exist, and since the lateral lines often contain an axial longitudinal vessel, I shall defer the further consideration of these developments of the deep cellular layer until I come to speak of the organs of circulation and the so-called 'water-vascular system.'

I have examined the integument most carefully in *Dracunculus medinensis*, and also in *Ascaris lumbricoides* and *A. megalocephala*, and in these last two animals have found it similar in almost all respects. In them its total thickness, as measured in transverse sections, is about $\frac{1}{125}''$; rather more than one-fifth of which is due to the thickness of the cellular layer, whilst the remaining portion is made up of the several chitinous lamellæ. The distinct recognition of this inner layer as something else than a mere granular membrane, and its absolute continuity with the lateral and median lines, is a matter of no small importance for the proper elucidation of Nematoid anatomy; and this layer also deserves our attention, since it seems to take an active share in the development as well as in the vital functions of these animals. It is not only the formative layer of the thick chitinous envelope, but, in all probability, it takes a most active part in the respiratory processes, since it communicates directly with the exterior, and contains within its substance the principal representatives of the vascular system of the Nematoids. In the *Ascarides* generally it is well developed, and is distinct also in the Guineaworm† and in *Spiroptera obtusa*, but it was found to be very thin in a species of *Filaria* and in *Prosthecosacter inflexus*.

In transverse sections of *Ascaris lumbricoides* or *A. megalocephala*, the direct continuity and similarity of tissue between this layer and the lateral and median prominences can be easily seen (Plate XXIII. figs. 5 & 16). After a portion of the body has been slit open and the longitudinal muscles have been stripped off, at first sight there appears nothing more than a mere granular layer situated on the external chitinous integument, the granules themselves consisting of rather large, highly refractive particles. But a more careful inspection reveals a number of larger ovoid or spherical cells about $\frac{1}{1250}''$ in diameter, and provided with a distinct nucleus (Plate XXII. figs. 13 & 14) scattered amongst the granules; and indeed it seems highly probable that most of this granular matter is either now contained in cells, or may be considered as the remains of cell formation*.

---

* *Loc. cit.* p. 380.

† This, which I was unable satisfactorily to demonstrate before, I have lately been able to make out, together with a few other additional facts, after the examination of some specimens in excellent preservation kindly given to me by Professor AITKEN.

A very few fibres appear to interlace amongst this material, though these are almost wholly collected into two distinct layers, the fibres in which have different directions, and are aggregated together so as to form a loose meshwork or fibrous membrane. The external and thinner of the two connects the cellulo-granular layer with the chitinous envelope, and its very delicate fibres have a transverse direction; whilst the internal membrane, made up of stronger fibres having for the most part a longitudinal direction, serves as an aponeurosis for the firm attachment of the great longitudinal muscles, and in the intermuscular intervals it constitutes the bounding membrane of the lateral and median lines.

The chitinous lamellæ are plainly divisible into five distinct primary layers, the most internal of which is the thinnest, and presents very faint, close-set, longitudinal markings (Plate XXIII. figs. 5, *e*, & 15). It seems rather more adherent to the enderon than to the next chitinous layer, and is often removed with the former when the integument is torn with needles. I have found nothing answering to this layer in *Dracunculus*. The next two layers are much thicker, though equal to one another, and similar in all respects, save that their oblique markings are in opposite directions (Plate XXIII. figs. 5, *d*, *c*, & 14). These layers can be split into a variable number of lamellæ, though not nearly with so much facility as the similar layers in the Guineaworm, which in this latter animal have also a greater proportional thickness. The markings (of the two layers) appear as bright lines whose directions intersect one another, at very acute angles, in different planes. The next layer, which is the thickest of all (Plate XXIII. fig. 5, *b*), seems absolutely homogeneous and without markings of any kind. This I have never been able to isolate from the adjoining layers, though it and the others, with their respective proportions, may be readily seen in thin transverse sections of a dried animal made with a sharp razor and subsequently mounted in acetic acid†. Examined with the polariscope and a selenite plate, the whole structure becomes still more distinct—the contiguous layers being accurately distinguished by bright and contrasting bands of colour. The external layer, like the last, does not seem capable of being split into thinner lamellæ, and though not so thick as this, is thicker than either of the others. It presents well-marked, broad, double contoured transverse lines (Plate XXIII. fig. 13). These are about $\frac{1}{1500}''$ apart, and mostly preserve a considerable parallelism with one another, except where it is disturbed by the bifurcation or commencement of one of the lines, as shown in the figure. They do not all therefore form perfect circles round the body, and differ from the corresponding markings in the Guineaworm by their altogether more regular arrangement and the greater number of these bifurcations[*].

---

* EBERTH (Untersuch. über Nemat. p. 46) seems to have recognized this structure as composed of delicate cells in the *Trichocephalidæ*, though he speaks of it as beneath the skin instead of forming one of its most important layers: he says, "Dicht unter der Haut trifft man eine zarte feinkörnige Schicht, die mir aus sehr zarten Zellen zu bestehen scheint."

† After making sections of the Nematoids, whether fresh or dry, I always place them in acetic acid previous to examination; it not only renders them more transparent, but, owing to the rapid imbibition of the fluid, it is the best means of restoring the circular form of the section. If the specimen is to be preserved, it should be soon taken out of the acetic acid and mounted in glycerine.

Whatever the nature of the alteration in the chitinous substance may be, giving rise to these markings, it seems to extend through the whole thickness of this outermost layer, and is doubtless a change similar to that causing the markings, not only of the other layers, but also of the chitinous lamellæ in the Nematoids generally. This change causes an alteration in the refractive power of the lamella; and in some instances, at least, I think there is evidence to show that this is due merely to an alteration in the thickness of the membrane, as seems certainly to be the case with the irregular markings of the integument in *Prosthecosacter inflexus*. In transverse section the lines are seen to correspond to actual ridges of the integument (Plate XXVII. figs. 4 & 5). In other cases, however, it may perhaps depend upon a mere alteration in density of the lamella in the situation of the lines, or even upon a diminution in thickness. The number and arrangement of the chitinous layers, and also the character of their markings, varies somewhat even in the different species of the genus *Ascaris*, and to a considerable extent in the Nematoids generally. The markings of the external layer, however, seem to afford a pretty constant generic character. In *Ascaris mystax*, where I have looked for it particularly, I have been unable to recognize the thin inner layer with the longitudinal markings. In transverse sections of the integument of *A. marginata*, a number of fine lines may be seen radiating outwards from the inner layers (Plate XXVI. fig. 1); these are remarkably numerous in this species, though they may be seen more distinctly owing to their increased size (especially in the lateral regions) in *A. lumbricoides* and *A. megalocephala*, extending from a slightly swollen base through the two outer layers. There seems to be no reason to believe that they are tubular, and they may be mere connecting perforating fibres. In *A. spiculigera*, in the intervals between the transverse surface lines, there are series of short connecting markings at right angles to them (Plate XXVI. fig. 17); whilst in a deeper layer, between the external one and those with oblique markings, are somewhat diamond-shaped markings, arranged in transverse series, and the same distance apart as the external circular lines[†]. In the genus *Strongylus* the most pronounced external markings are longitudinal, though these are intersected by very delicate transverse ones.

---

[*] These markings must not be confounded with the apparent circular markings seen by the naked eye, which are due as it were to wrinkling of the integument, and between any two of which would be included from thirty to seventy of the circular lines described above.

[†] These are referred to by DUJARDIN as "*des séries assez régulières de lacunes.*"—Loc. cit. p. 206.

This I have seen most plainly in individuals from the stomach of a hare (Plate XXVII. fig. 10), though I have recognized a similar arrangement less distinctly in *S. filaria* and *S. auricularis.* In *Trichocephalus affinis*, in place of the two layers with oblique intersecting lines, there is a single layer with transverse lines of a similar character, though quite different from the more pronounced markings of the surface layer. In a species of *Filaria* examined, I could detect only a thin external layer with transverse markings, and a thick structureless portion, apparently devoid of markings, intervening between it and the very thin cellular layer; whilst in *Prosthecosacter inflexus* only one structureless and very transparent glass-like epidermic layer exists, which being developed into ridges in an irregular manner upon its surface, causes it to exhibit a similar arrangement of lines or integumental markings when seen by transmitted light (Plate XXVII. figs. 4 & 7). In this animal also the deep skin layer is remarkably thin.

The integument of the free Nematoids is evidently formed upon the same type, but I have distinctly recognized oblique intersecting lines in the internal layers of *Dorylaimus stagnalis* only. DUJARDIN has also represented these. In this animal there are no transverse markings of the external layer, but well-marked longitudinal ones. The representatives of other genera, such as *Enoplus* and *Chromadora*, present both transverse and longitudinal lines, the former being most pronounced in the genus *Chromadora* and the latter in *Enoplus*; whilst in *Plectus*, *Trilobus*, and many other genera transverse markings only are seen.

In the genera *Cyatholaimus* and *Spilophora* we meet with circular rows of dots instead of lines, and in several genera, such as *Leptosomatum*, *Phanoderma*, &c., no integumental markings whatever can be recognized. The cellular enderon I have not detected in these animals*, except as it exists in the lateral regions of the body, where it constitutes the lateral bands. These animals are so small that the difficulty of making satisfactory transverse sections has hitherto been insuperable.

In both the parasitic and the free Nematoids the chitinous portion of the integument is occasionally developed into alæ or other projections; these are cervical in *Ascaris mystax*, and principally composed of a development of what is generally the thickest layer, viz., the second from without inwards. But these developments more commonly exist as caudal expansions in the male, such as are so well known in the genera *Strongylus* and *Spiroptera* amongst the parasitic species. Structures of a similar nature may be seen amongst the free Nematoids in the genus *Rhabditis*, where the lateral alæ are supported by sets of delicate rays†, and in *Tylenchus*, where they are less developed and unsupported by such processes‡.

The development of the external layers of the integument into spines is not an unfrequent occurrence amongst the parasitic Nematoids; these are somewhat conical, and thickly arranged in transverse rows in *A. echinata*; exist as an innumerable quantity of recurved hooks on the anterior part of the body of a species of *Spiroptera* found by Mr. BELLINGHAM in *Anas tadorna*; as circular groups of palmate spines in *Gnathostoma spinigerum**; and as acute recurved spines arranged in a quincunxial manner on the anterior part of the body of *Hystrichis tricolor.* In *Trichosomum tomentosum,* DUJARDIN found a portion of the body clothed with a multitude of very minute, spreading, hair-like processes. Amongst the free Nematoids, and more particularly the marine species, hair-like processes or setæ are very abundant, existing principally as circlets round the head, and in linear series on the ventral region of the caudal extremity of many males. They are often scattered more sparingly over other parts of the body, and altogether seem to reach their maximum development, so far as I have observed, in *Sphærolaimus hirsutus*†. These setæ of the free Nematoids seem to take the place of the spines in the parasitic species, as the latter structures are not met with in either marine, land, or freshwater representatives.

---

* Unless, as seems most probable, the almost superficial cells met with in many species of the genus *Cyatholaimus* (Plate XXVIII. fig. 36), giving them their characteristic maculated appearance, do in reality belong to this layer.

† Trans. of Linn. Soc. vol. xxv. pl. 10, fig. 62.

‡ Ibid. pl. 10, fig. 114.

Papillæ and Suckers.—These organs, either separate or combined, are of very common occurrence in connexion with the integument, both among parasitic and free Nematoids. They exist in two principal situations—around the head, and about the caudal extremity of many males. Some of the organs met with in the latter situation are undoubtedly suckers, though with regard to other structures, both in this region and around the mouth, it seems by no means clear whether they should be considered simply as papillæ, or whether they are also suctorial.

The cephalic papillæ can be well studied in *Ascaris lumbricoides,* though their number and arrangement appear to be nearly the same in all the species of this genus. Two exist on the dorsal head lobe (one on each side), and one in the middle of each latero-ventral lobe (Plate XXII. figs. 14 & 19). In *A. lumbricoides* they present the following structure; externally there is a convex projection of the chitinous envelope with a minute perforation in its centre, running down to a depression in the apex of a well-marked, bluntly conical projection of the deep cellular layer (Plate XXII. fig. 17), which with some fibres (mainly nerves ?) constitutes the central parts of these lobes‡. These latter are essentially skin development formed around and enclosing the triradiate mouth, and do not contain well-marked prolongations of the great longitudinal muscles as stated by KÜCHENMEISTER. The papillæ which they bear, therefore, may be simple tactile organs, or they may be partly suctorial. In *Spiroptera obtusa* there are six cephalic lobes, each of which bears a single papilla. Well-developed papillæ exist around the mouth in the genera *Cucullanus* and *Sclerostomum,* and more simple ones in the genera *Dracunculus* and *Filaria.* Amongst the free Nematoids they are best developed in the genus *Enoplus.* I cannot say, however, whether the cephalic papillæ are perforated in the same way in the members of these other genera as I have found them to be in those of *Ascaris.*

---

* DIESING's *Cheiracanthus robustus.*

† Trans. of Linn. Soc. vol. xxv. pl. 13, fig 192.

‡ "Cock's-comb-like structures."—KÜCHENMEISTER (Syd. Soc. Transl.), p. 411.

Papillæ agreeing in all respects with those described above, save that the external aperture is oftener in the centre of a slightly concave depression rather than of a convex eminence, are met with in single or double series in the ventral region, above the ano-genital aperture of male *Ascarides.* In *A. lumbricoides*, on the posterior part of the body, for a length of 1½″ there are about forty of these papillæ on each side of the ventral region (Plate XXII. fig. 20). The anterior ones, gradually diverging more to the lateral aspect of the body, are in single file and about ⅛″ apart, but posteriorly they are closer together and the linear arrangement is not preserved. These papillæ may be well seen in transverse sections (Plate XXIII. figs. 3 & 4, *l*, *l*). I have seen well-marked suctorial papillæ also in the males of *Heterakis acuminata* (Plate XXII. fig. 13) and *Oxyuris vermicularis*; and besides bodies of this nature, in *Cucullanus heterochrous* there is also a very large and prominent sucker-like body in the mid-ventral region. In the same situation, a large and peculiar body of a similar nature is found in *Heterakis vesicularis**. In short, structures of this nature seem much more commonly present than absent in the males of parasitic Nematoids, whilst in the free species the reverse condition appears to obtain. Such bodies are, nevertheless, well developed in the genus *Leptosomatum*†, whilst a series of integumental channels variable in number exist in the same region of most *Dorylaimi.* The bodies which I have called "supplemental organs" existing in the males of the genera *Enoplus*, *Phanoderma*, and *Anticoma*, seem altogether problematical in their nature‡.

In the free Nematoids we meet with an organ fully in harmony with the requirements of these animals, but which, from their different mode of life, neither exists nor is needed in the parasitic species. I allude to the terminal tail-sucker which is found in both sexes in nearly all the marine species, and in those of about half the land and freshwater genera. It is the only kind of organ of prehension with which these minute animals are provided, and is rendered all the more necessary by the smooth and polished nature of their integuments. It is most constant, too, and best developed just in those species which require it most—in those living amongst the sand and stones of the sea-shore, in its surface-mud, or tenanting the fine weeds in its rock pools, which day by day are exposed to the ever-moving currents raised by wind and tide, and which would be continually swept from their natural haunts were they not provided with some means of attaching themselves to surrounding objects. In its simplest form, such as we find it in the members of the freshwater genus *Mononchus*, all we can recognize is a very slight roundness and increase of size in the narrow terminal extremity, with a central aperture; but where it is more developed, as in the genus *Enoplus*, or *Leptosomatum*, in addition to the terminal extremity being slightly swollen, we see the terminal aperture continued inwards as a canal, and terminating after a short distance at a more solid though perforated portion, to which are attached three pyriform sacs or elongated tubes§. In the genus *Enoplus* these sacs occupy the cavity of the body posterior to the anus, and are of an elongated pyriform shape; whilst in other species, as may be well seen in *Oncholaimus vulgaris* and in the *Leptosomata*, they are still more elongated and tubular in form, and extend for some distance into the cavity of the body by the side of the intestine. These appendages only exist in species having otherwise large and well-developed suckers, and their main function seems to me most likely to be connected with the more efficient action of these structures. According to the views of LEYDIG and EBERTH[*], these sacs are "tail-glands" (Schwanzdrüse) opening by a terminal "papilla" and secreting a clear gummy substance, which enables them to adhere to surrounding objects. I do not think this mechanism of adhesion a very probable one; and although in a specimen of *Oncholaimus vulgaris* I have seen expelled from these bodies through the terminal orifice, at irregular intervals, small quantities of fluid rendered apparent by the minute molecules suspended in it, still their generally clear appearance, and the absence of all the main characters belonging to glandular structures in other parts of the body, lead me rather to discountenance this view of their nature. Instead of "glands" I would term them *sucker-tubes*, believing them to be contractile in their nature and mainly destined to perfect the action of the sucker, which seems to operate by the ordinary principles of hydrostatic pressure, rather than by the adhesive properties of gummy secretions.

---

* Würzb. Naturwiss. Zeitsch. Erst. Bd. 1860, Taf. ii. 2 (Eberth).

† Trans. of Linn. Soc. vol. xxv. pl. 12, fig. 163.

‡ See figures, *loc. cit.*

§ See figures, *loc. cit.*

Integumental pores.—In *Dorylaimus stagnalis* I first detected a number of minute channels through the integument, and though I have since recognized these in many other free Nematoids (especially in the larger marine species), in no animal can they be so well observed as that in which they were first discovered. The thickness of the integument, and the number of the pores in the lateral regions of the body of this animal, are the reasons which make it so suitable for examination. They seem to be very numerous over those portions of the lateral regions of the body, from end to end, corresponding in position with the internal lateral bands. Those, however, situated towards the posterior extremity of the body are most favourable for examination, owing to their increased number, size, and distinctness in this situation (Plate XXVIII. figs. 3 & 4). Extending through the chitinous portion of the integument they are about $\frac{1}{2000}''$ long, capillary in breadth, commencing internally opposite a conical projection of the true skin, and terminating at the external surface in a minute depression. That these are channels through the integument I have not the slightest doubt. I have detected similar pores in another freshwater species (*Tripyla glomerans*) having an unusually thick integument; in this also the pores were in the lateral regions of the body, though they did not exist in nearly so great abundance as in *Dorylaimus stagnalis*. Amongst the marine species I have recognized similar integumental channels most plainly in *Leptosomatum gracile*, *L. figuratum* (Plate XXVIII. fig. 33), and in *Phanoderma Cocksi* n the lateral cervical regions, though also less distinctly in the lateral region throughout the body. In addition they occur along the mid-dorsal and ventral lines of the *Leptosomata*. In *Oncholaimus vulgaris* they also exist in the mid-ventral and dorsal regions, as well as in the lateral, and I have seen them in the former situations only in members of the genus *Enoplus*.

---

[*] Untersuch. über Nemat. 1863, p. 8.

Eberth * seems to have recognized similar structures in a species of *Leptosomatum* (his *Phanoglene bacillata*), though he put a different interpretation upon what he saw, and called the structures "skin-glands" (Hautdrüse). It must be admitted that the recognition of their real nature is not so easy in the marine species as it is in *Dorylaimus stagnalis*. In this latter their nature scarcely admits of a doubt; but the homology of the structures to be seen in this animal with the almost similar structures which may be detected in many of the marine species, as well as in the *Trichosomata*, is also unquestionable. I have found these channels made much more apparent after the integument has been swollen somewhat, and rendered more transparent by immersion of the animals in strong glycerine for about twenty-four hours†. Although only yet detected in the larger species, I suspect these pores exist in a considerable proportion of the free Nematoids. There seems to be, however, evidence to show that none such are present in the representatives of the four genera *Tylenchus*, *Cephalobus*, *Aphelenchus*, and *Plectus*. Concerning the species of these genera I shall have to speak further on, and also of the probable use of the integumental channels to those species in which they exist.

In one only of the parasitic Nematoids have I seen a very close approximation to this arrangement of the integumental channels, and that was in *Heterakis acuminata* from the frog. In this animal similar integumental pores may be seen, apparently in single file, along the lateral aspects of the body (Plate XXII. fig. 12), about $\frac{1}{285}''$ apart. On the caudal extremity of the males these seem to be still more numerous and scattered over the surface generally, in addition to the well-marked ventral suckers met with in the same individuals (Plate XXII. fig. 13, *c*). But in the genera *Trichosoma* and *Trichocephalus* such pores are extremely numerous, and give rise, more particularly in the species of the latter genus, to an altogether exceptional appearance which has long been a puzzle to anatomists; although, on the other hand, in many species of the genus *Trichosoma* there is a much closer resemblance to what we meet with amongst the free Nematoids.

Dujardin, describing *Trichocephalus dispar*, speaks of the integument as "strié transversalement avec une bande longitudinale hérissée de petites papilles." Wedl and Küchenmeister ‡ give confusing and rather unintelligible statements concerning the same structure; but Dr. Cobbold, in his recent work §, after alluding to these various opinions as to the nature of the peculiar widening band extending along one side of the body in different species of *Trichocephalus*, speaks in the following definite manner concerning this, as met with in *T. affinis*:—"According to my own observations this band is a genuine structure, and is made up of projecting, bluntly-pointed, polygonal epidermal cells, which in certain adjustments of the focus refract transmitted light so strongly that the band looks as if it consisted of a regularly arranged series of pigment spots (fig. 3, *a*); at other times the centre of each cell becomes clear (*a*), and the irregular polygonal character of each individual cell is rendered more apparent." Dr. EBERTH seems to have examined most carefully many species of the genera *Trichocephalus* and *Trichosoma*, and has also expressed very concise opinions concerning these bands of which we have been speaking. According to him [*], these appearances are caused by solid staff-like prolongations into the substance of the skin, given off from and situated upon certain closely-packed, cylindrical, or elongated-polygonal cells,—the whole structure representing a variety of the dorsal median line as it exists in these Nematoids. He seems to think that the prolongations are developments from the cell-wall, and is decidedly of opinion that they are solid.

---

* Untersuch. über Nemat. pp. 8 & 19, pl. 2, fig. 1.

† This is by far the best medium in which to mount the free Nematoids—at all events for species which are not less than $\frac{1}{10}''$ in length. At first they shrivel up, and the specimens appear to be ruined; but after from twenty-four to forty-eight hours the glycerine has passed into their interior, causing them to resume their natural form, and making them very transparent. So mounted they undergo little change.

‡ Manual of Parasites (Syd. Soc. Transl.), pp. 325, 326.

§ Entozoa: an Introduction to the Study of Helminthology, 1864, p. 71.

After the most careful examination of *Trichocephalus dispar*, *T. affinis*, and *Trichosoma longicolle*, I am unable to agree with any of these observers.

More than twelve months ago, before knowing anything of EBERTH's observations (which do agree in some respects with my own), I was enabled to discover what I believe to be the real nature of these structures, during the examination of a specimen of *Trichocephalus dispar*, whose integument had been rendered more transparent by boiling the animal for two or three minutes in dilute acetic acid. Certainly there are no actual elevations of the integument into "papillæ" in the region of the band [†], though the transverse markings decidedly cease at its borders (Plate XXVII. figs. 15 & 17); neither are there any "epidermal cells," as described by Dr. COBBOLD, and indeed their presence is quite irreconcileable with the chitinous nature of the epidermis in the Nematoids generally: both these appearances are, I believe, purely optical delusions, owing to errors of interpretation. I differ from EBERTH with respect to the description he gives of this band in one point only, though that is a most important one. What he considers as solid staff-shaped prolongations I believe to be integumental channels, essentially similar to those which I have previously described as so common in the free Nematoids. This would scarcely be imagined from an examination of the band throughout the greater part of its extent; but its posterior termination is by no means abrupt, and in that region its constituent elements are scattered widely apart and are quite isolated from one another before they entirely disappear on the thicker portion of the body. An examination of this region permits these integumental channels to be seen under different aspects (Plate XXVII. fig. 16), and enables their real nature to be more clearly perceived. When the mouth of the channel is looked down upon, and brought into focus at the surface of the integument (where it corresponds with a minute depression), it appears as a bright circular space about $\frac{1}{15000}''$ in diameter; and as the focus is lowered a dark roundish or polygonal halo is developed around it, giving rise to an appearance which led Dr. Cobbold to speak of epidermal cells with clear central spaces. This dark border I believe to be due simply to an alteration in the diffraction of light by the bounding walls of the integumental channel, and the upper extremity of the columnar cells beneath coming into focus as the object-glass is lowered. In the *Trichocephali*, only one such band exists in the dorsal aspect of the anterior part of the body; but in the various species of the genus *Trichosoma* more commonly two exist, which may be either dorsal and ventral, or lateral[*]. In the members of this genus the pores are frequently not nearly so numerous, and in *Trichosoma longicolle* at least (the only specimen that I have examined), both these and the cellular bands beneath seem to approximate very closely to what we meet with in the free Nematoids (Plate XXVII. fig. 14); and in which also, as just stated, we see the same variation as regards the situation of the integumental channels.

---

[*] Untersuch. über Nemat. 1863, p. 46.

[†] Unless we so term, with DUJARDIN, certain larger rounded prominences of the integument often seen bounding the band in some portions of its length—"papilles plus grosses qui se gonflent par endosmose." These are altogether unimportant structures, due simply to a partial separation (such as we may often meet with in the Nematoids) of the most superficial lamella of the epidermis from that beneath it.

Yet other openings through the integument remain to be spoken of, which, so far as I have observed, exist only in the parasitic species, and of these never in the *Trichocephali*, *Trichosomata*, or *Heterakis acuminata*. I allude to two lateral openings, of a much larger kind than those previously described, situated one on each side of some portion of the œsophageal region of the body, and two posterior latero-ventral openings, of the same character, between the anus and the posterior extremity of the animal[†]. These structures have been observed both by Schneider and Eberth; by the former they have been described respectively as "cervical and caudal papillæ"[‡], and by the latter as openings of the water-vascular system[§]. In many of the Nematoids in which they are met with, these structures do present such an appearance as to lend support to Dr. Schneider's view as to their nature, inasmuch as they are almost identical in their structure with the ventral papillæ of male *Ascarides*, consisting generally of a conical projection of the deep layer of integument into the inner part of the chitinous layer, where it is in connexion with a distinct channel through this substance opening in the centre of a surface-depression. But in *Ascaris lumbricoides*, the animal in which, quite independently, I first recognized these openings, the anterior channels through the integument are altogether so marked and well developed in proportion to the granular projection (Plate XXII. figs. 14 & 16), that from the first I looked upon the integumental pore as the essential portion of the structure, and have never considered them to be tactile papillæ. This impression regarding their nature is rendered even more probable by what we see in *Prosthecosacter inflexus* (Plate XXVII. figs. 1 & 2). It seems, moreover, difficult to imagine what could be the use of papillæ in these situations, though it does appear to be a pretty constant rule amongst the Nematoids for the deep cellular layer of the integument to communicate with the exterior by means of channels through the chitinous envelope. No fine integumental pores, such as we have hitherto described, exist in the majority of the parasitic Nematoids, but so far as we have examined, both EBERTH, SCHNEIDER, and myself have found in these animals the larger cervical and caudal openings. May they not be looked upon as in a measure substitutes for one another? This opinion is also supported by the fact that the surface-depression into which they open is occasionally so marked as to discountenance the idea that they are to be looked upon as papillæ. The view entertained by EBERTH, that these pores are openings of the water-vascular system, I have no hesitation in believing to be erroneous. SCHNEIDER also is quite opposed to this interpretation of their function. After repeated examinations I have quite satisfied myself that, though situated externally to the lateral bands, these integumental channels have no communication with the longitudinal vessels often contained within them. Such pores exist on *each* side of the cervical region of *Ascaris osculata*, though vessels are present only on the left side (Plate XXVI. fig. 9); and again, in *Cucullanus heterochrous*, the caudal pores are distinctly posterior to the cæcal terminations of the lateral vessels* (Plate XXVII. fig. 12, *a* & *b*).

---

[*] Eberth, Untersuch. über Nemat. Taf. vi. u. vii.

[†] Two similar lateral openings are spoken of by Eberth in *Spiroptera uncinata* as existing near the middle of the body, posterior to the vagina. I have seen such median openings also in one species, but having made no note of it at the time, cannot be quite sure as to the animal in which they were seen—I think, however, it was in *Strongylus filaria*.

[‡] Neue Beit. zur Anat. und Morph. der Nematoden, Reich. and Du Bois-Reym. Archiv, 1863, p. 15.

[§] Würtzb. Naturwiss. Zeitsch. 1860. Erst. Bd. Taf. ii. 3 *a*, u. Taf. iii. 13 *a*; Untersuch. über Nemat. Taf. viii. u. ix.

In *Ascaris lumbricoides*, in addition to the papillæ already described as existing on its cephalic lobes, I have detected certain integumental channels of two kinds; the first being two in number, and situated one on each side on the latero-ventral lobe, near its upper border and anterior to the level of the larger central papilla (Plate XXII. figs. 14 & 19, *c*). At these points the cellulo-granular layer is formed into a conical projection which reaches the surface at a slight depression in the chitinous envelope (Plate XXII. fig. 18, *c*, *d*), and communicates with the exterior by means of a small circular aperture. The other channels (two on the anterior border of each lobe) are very minute, and are mere capillary passages through the thick chitine in this situation (Plate XXII. figs. 18 & 19, *e*, *e*), with no apparent projection of the cellular layer beneath. In all probability both these kinds of channels are to be met with in the cephalic lobes of other *Ascarides*.

---

* In a species of *Dispharagus*, from the gizzard of *Colymbus septentrionalis*, I found the caudal openings, though I could not recognize the cervical. I did find, however, in this region, on each side of the body, a projection of the chitinous integument (Plate XXII. fig. 1). KÜCHENMEISTER represents lateral cervical projections of this kind also in *Anchylostomum duodenale*, and I have likewise seen them in a red-coloured *Strongylus* from the stomach of a hare. I was, however, unable to recognize perforations through these structures. In the females of the last-mentioned animal also the two caudal pores seemed to be replaced by a large number of integumental channels distributed over the whole circumference of this region of the body; though in the males two well-marked lateral pores were visible just above the level of the bursal expansions. They are very long, on account of the thickness of the integument in this region.

In many of the free Nematoids peculiar circular markings are met with close behind the head, on either side of the body; in others, compressed spiral instead of circular markings exist; whilst in some, circular depressions or convex projections are substituted for these markings, in the same region[*]. I have examined these structures most carefully with one of POWELL and LEALAND'S $\frac{1}{25}''$ object-glasses, but could never detect any aperture or internal vessel in communication with them; they seemed to be simple markings, elevations, or depressions of the integument unconnected with any other structure. In the members of the genus *Plectus*, however, somewhat similar markings exist, which are undoubtedly connected either by a minute pore or by a thinning of the integument in this situation, with the anterior extremity of a lateral vessel (Plate XXVIII. fig. 14).

It seems now to be an undoubted fact that, during the period of growth of the Nematoids, both free and parasitic, a periodical shedding and renewal of the chitinous portion of their integument takes place. This was I believe first recorded by EHRENBERG as occurring amongst the free Nematoids. Amongst these I also have seen animals belonging to several genera with the old integument separated from, though still more or less investing the animal, as well as at an earlier stage, when the demarcation between the old and the new chitine is indicated by a sharply defined undulating line. In some species of the genera *Oncholaimus* and *Cyatholaimus* it seems to separate in distinct shred-like pieces instead of being thrown off entire. In the genus *Enoplus* the three teeth are shed and renewed with the integument. Amongst the parasitic species I have seen a specimen of the so-called *Filaria piscium* completely shed this same chitinous portion of its integument, which phenomenon has also been described by DUJARDIN as occurring in *Hystrichis tricolor*, and by DIESING in *Ascaris depressa*.

MUSCULAR SYSTEM.

Almost all Nematoids seem to possess four great longitudinal muscles running along the whole length of the body, and separated from one another only by the lateral and median lines. In the species, however, in which the median lines do not exist, there is often no distinct separation between the two dorsal or the two ventral muscles, and accordingly it has been asserted by some that two great longitudinal muscles only exist, an upper and a lower. With regard to the presence or absence and distribution of transverse fibres, much difference of opinion has existed. CLOQUET[†] has described transverse muscular fibres external to the longitudinal in *Ascaris lumbricoides*, and OWEN[‡] the same in *Strongylus gigas*; both speak of the close adhesion of these to the chitinous integument. DE BLAINVILLE[§] speaks of transverse fibres internal to the longitudinal, and Von SIEBOLD[||] doing the same, correctly points out that these do not form complete rings, but are as it were separated into four segments by the longitudinal lines.

---

[*] See figures, *loc. cit.*

[†] Sur les Vers Intestinaux, 1824, p. 17.

[‡] Cyclop. of Anat. and Phys., Art. *Entozoa*, p. 129.

[§] Dict. des Sc. Nat. tom. iii. App. p. 40.

[||] Manuel d'Anat. Comp. note, p. 119.

These transverse fibres, such as are alluded to by SIEBOLD, have been looked upon as vessels by BOJANUS*, CLOQUET, DIESING†, WALTER‡ and others, whilst they were suggested by MEISSNER§ to be branches of the peripheral nerve-trunks, similar to what he erroneously considered to be the nature of homologous processes in the *Gordiaceæ*. SCHNEIDER and EBERTH, as well as myself, are quite agreed as to the nature of the transverse fibres described by SIEBOLD, and in speaking of the histology of the muscles, I shall fully describe their origin and distribution.

In addition to these principal muscles extending through the body generally, there are other smaller local fasciculi, some common to both sexes, for the opening and closure of the anal cleft, whilst others are peculiar to the male. They are, besides bundles for the protrusion and retraction of the spiculi, a series of fibres—always well marked in the genus *Ascaris*—extending on each side, for some distance above the ano-genital opening, from the lateral bands to the mid-ventral region and median line (Plate XXIII. figs. 3 & 4). These are most developed, and constitute gradually thicker bundles posteriorly. In *A. osculata* they attain an enormous development, and separate the longitudinal muscles into three nearly equal bands ‖, their extremities completely obliterating and occupying the place of the mid-ventral and lateral lines (Plate XXVI. fig. 12). In *A. lumbricoides* these peculiar fibres may be met with in the males for about a distance of 1½″ from the posterior extremity of the body, so that the extent of their distribution corresponds exactly with that of the ventral papillæ before described; which leads me to believe them to be destined to flatten the ventral region of the male, and so enable the papillæ, whether suctorial or simply tactile, to be brought into contact with the body of the female when the posterior extremity of the body of the male is coiled round it *in actu coitûs*.

The bands of longitudinal muscles vary much in thickness in different species; they are much more developed, for instance, in *A. megalocephala* than in *A. lumbricoides*, and in the males, of all species of *Ascaris* at least, form much thicker bands than in the females. In the male the cavity of the body frequently becomes much diminished, owing to the encroachment upon its area by the four thick convex longitudinal masses of muscle.

We are indebted to Dr. SCHNEIDER¶ for a most accurate account of the histological structure of the muscles in the Nematoids, and though his views have been questioned by Walter, the results of my own researches are mostly in accordance with them, and Eberth* has also testified to their correctness.

---

* Isis, 1821, p. 187. pl. iii. figs. 51 & 54.

† Annal. d. Wiener Mus. ii. part 2, pl. xvi. fig. 1, et pl. xviii. fig. 2.

‡ VIRCHOW's Archiv, 1862, Bd. xxiv. p. 166. Taf. iii.

§ MÜLLER's Archiv, 1856.

‖ These three bands are produced in this manner:—in the male Nematoids, towards the posterior extremity the lateral lines deviate from their median position and run closer to the dorsal surface. Here also the dorsal median line is often wanting, and the two diminished dorsal muscles blend into one band, about equal in size to each of the ventral longitudinal muscles, and so produce an arrangement similar to what MEISSNER has described as generally existing in the genus *Mermis*.

¶ MÜLLER's Archiv, 1860, S. 224.

Speaking generally, the longitudinal muscles may be said to be composed of a series of small muscle-cells varying in form between an elongated spindle and a rhomboidal shape, each of which is composed of one portion (cortical) altered in structure by its conversion into fibrillæ, and another less altered portion varying in its proportional extent, containing in the midst of the granular medullary substance of which it is composed one or more nucleated cells, and often sending off a transverse prolongation to, or in the direction of, one of the median lines. In their most divergent types two well-marked differences exist in the nature of these muscle-cells in different species of Nematoids, though intermediate states may be seen, which clearly point out these varieties to be nothing more than modifications of one common plan. This distinction was first noted by Dr. Schneider, and he proposes to divide the Nematoids into *Platymyariæ* and *Colomyariæ*, according as they agree most with one or other of these types of muscle-formation. As illustrations of the first type, we have the *Spiropteræ*, *Strongyli*, and *Oxyurides*, whilst the second is seen to perfection in the members of the genus *Ascaris*.

Beginning with the simpler forms, the *Platymyariæ*, we may take the *Spiroptera obtusa* as a good illustration. In this animal the muscle-cells are flat, and of a somewhat elongated rhomboidal form†, accurately dovetailing in with one another so as to form four continuous layers separated from one another by the longitudinal lines‡. On the surface they have a granular aspect, and present a nucleated cell generally near the centre imbedded in this granular material. By the aid of thin transverse sections of the animal we obtain a much clearer insight as to the precise structure of each muscle-cell§, and are enabled at once to see that each is composed of an external solid contractile portion, and an internal granular matter bounded by a loosely fibrous envelope (Plate XXVI. fig. 21). We shall speak more fully of these various parts after having described their modifications met with in animals of the other type.

The structure of the muscles in the *Colomyariæ* may be well studied in any of the *Ascarides*, and in none better than in *A. lumbricoides* and *A. megalocephala*, where the type attains its greatest complexity. Whilst in *Spiroptera obtusa* the breadth of each muscle-cell at its widest part considerably exceeded its depth or thickness, in these animals, on the contrary, the depth considerably exceeds the breadth, and they exist as triangular cells with a more or less elongated base (Plate XXIII. figs. 8 & 9), by which they are attached to the deep integumental layer, whilst their other sides and apices, from which certain processes are given off, project into the general cavity of the body*. These several cells are in close apposition with one another, and are accurately dovetailed together, as can be well seen in transverse sections (Plate XXV. fig. 13); these also show that the attached portion is the narrowest part, the free edges being thicker and rounded. The section of each bundle, according to its size, exhibits more or less granular matter in its centre, which in the smaller and medium-sized bundles is completely enclosed by the striped fibrous portion of the cell, whilst in the larger the central cavity and contained granular matter become more distinct and communicate with a more or less pronounced, bladder-shaped, fibrous prolongation (Plate XXIII. figs. 5 & 8). Now if we imagine the sides of one of the flat cells described in *Spiroptera obtusa* to grow up, approximate to one another, and close in completely over the granular matter except at its central portion, we should have a formation similar to that just described as actually existing in the *Ascarides.* A section of either extremity of the cell would also show granular matter completely enclosed by the fibrous contractile portion, whilst one through its centre would reveal a continuity between its central cavity and that of a small fibrous prolongation from it. The two forms are thus seen to be only modifications of a common plan, between which a complete series of transition states can be recognized in the structure of the muscle cell as met with in other different species of Nematoids (Plate XXVI. fig. 3). When one of these triangular cells of the *Colomyariæ* is seen lying on its side, it seems to be made up of a number of fine fibres, having a longitudinal direction and a parallel closely packed arrangement, with no trace, however, of transverse striation (Plate XXIII. figs. 8 & 9). But in transverse sections it is seen that what appear to be simple fibres when viewed from the exterior, are in reality a series of band-like fibres, each of which extends from the exterior to the central granular matter of the cell (Plate XXV. fig. 13). No appearance can be detected leading one to believe that these apparent bands are composed really of transverse rows of narrower fibres. This structure of the contractile portion of the body of the muscle-cell is essentially similar in both *Colomyariæ* and *Platymyariæ.*

---

* Untersuch. über Nemat. 1863, p. 64.

† Untersuch. über Nemat. Taf. ix. 3.

‡ Schneider has pointed out what he considers to be the general arrangement of these muscle-cells in the *Platymyariæ*, after what he has more especially observed in *Oxyuris curvula*. (Reich. and Du Bois-Reym. Archiv, 1863.)

§ There is a great apparent difference in the size and breadth of contiguous cells, simply owing to the section having passed through these in most cases at varying distances from their central or broadest part—a section which passes through nearly the centre of one cell may intersect the narrow extremity only of the next.

Much difference exists, both amongst the two groups and in the several members of each, as to the degree of complexity of the remaining processes of the muscle-cell. They are usually more simple in the *Platymyariæ.* But in Nematoids generally we may, I think, recognize two distinct varieties of these processes, the one being more or less developed representatives of the bladder-like growths so distinct in *Ascaris lumbricoides*, and the other answering to the transverse processes (Fortsätzen) extending from the muscle-cells to the median lines—also well developed in the same animal (Plate XXIII. fig. 2). The bladder-like processes are frequently but very little developed, and may be seen in their simplest condition in *Spiroptera obtusa*, where they are merely the internal bounding portions of the muscle-cell, composed of fibrous walls (Plate XXVI. fig. 21) enclosing the granular matter and contained nucleated cell, which rest on its proper contractile portion. In *A. lumbricoides*, on the contrary, they are more developed than I have met with in any other Nematoid. In this animal they correspond to the "appendices nourriciers" of Cloquet. The granular matter of the muscle-cell is here enclosed on all sides by the contractile portion, except at one point corresponding to its apex, and in this situation there is a bladder-shaped development communicating with the medullary portion of the cell only by a more or less narrow connecting isthmus (Plate XXIII. figs. 5, *n*, & 8). There seems to be a direct continuity between the body of the cell and the simple fibres composing the parietes of these bladder-like portions. In *Ascaris lumbricoides* these prolongations exhibit also a fibrous network in their interior, amongst the meshes of which are contained numerous bright highly refracting granules (Plate XXII. fig. 22). In *Dracunculus medinensis* these internal fibres are still more developed into smaller and stronger loculi, in the midst of which is situated the nucleated cell (Plate XXV. fig. 15). From the surface of the bladder in *A. lumbricoides* numerous delicate fibres are given off, which serve to connect this with similar neighbouring processes, and with the axial intestinal canal in the first part of its extent.

---

* After maceration for two or three weeks in dilute nitric acid the muscles are readily resolved into their component cells.

The other kind of process arising from the muscle-cells consists of narrow band-like prolongations, proceeding in a direction at right angles from the muscle-cell to the adjoining dorsal and ventral median lines, where these are present. They necessarily vary in length according to the distance between the longitudinal line and the muscle-cells from which they emerge. They are the "transverse muscles" of De Blainville and Von Siebold, and the vessels or nerves of other writers. In *Ascaris lumbricoides* their direction and arrangement can be well seen in transverse sections. In this animal some of the muscle-cells appear to give rise to transverse processes only, whilst in others a bladder-like prolongation may be seen as well. These transverse prolongations are composed of fibres and intermixed granules (Plate XXV. fig. 13), and are apparently directly continuous with the body of the muscle-cells, as originally stated by Schneider, though Walter[*] has since denied this. Eberth's[†] views are in accordance with those of Schneider and myself. The nucleated cell of the medullary substance is situated close to the origin of the transverse process, where this exists. In different Nematoids a great variation is met with in the abundance of the transverse processes, and generally they may be best studied, on account of their simplicity, in the *Platymyariæ*. Eberth has well represented them as they exist in *Heterakis vesicularis*[‡], whilst in *Spiroptera obtusa* they are less developed still, leading on to what obtains in other Nematoids where they are absent altogether. This is the case according to Eberth in *Ox. ambigua* and *A. oxyura*, and according to Schneider in *Pelodytes strongyloides* and some of its allies. I have never met with them either in *Dracunculus medinensis*, or in any of the free Nematoids.

As before stated, in many Nematoids no median dorsal and ventral lines exist, though the transverse processes are by no means necessarily absent in these same animals, as I have well seen in *A. osculata*. In this species there is a distinct slightly sinuous interspace between the two great longitudinal muscles in the mid dorsal and ventral regions in the usual situation of the longitudinal lines, and the transverse muscular prolongations are seen tending towards it, over which some of those from opposite sides unite with one another instead of having a common attachment to the ordinary longitudinal projections of the skin in this situation, whilst others seem to bend down to attach themselves to the skin exposed in this muscular interspace.

---

[*] Virch. Archives, 1860.

[†] Untersuch. über Nemat. 1863, p. 67.

[‡] Würzb. Naturwiss. Zeitsch. 1860, Erst. Bd. Taf. iv. 22.

In *Prosthecosacter inflexus* the muscle-cells, when seen in transverse section, are found to be extremely narrow as compared with their depth, and present the appearance of closely packed bundles with the usual transverse markings (Plate XXVII. fig. 5). But whether these animals are to be looked upon as *Platymyariæ* or *Colomyariæ* seems altogether doubtful—at all events I have never been able to recognize any granular matter between pairs of bundles, as would be the case if they belonged to the latter type. A small amount of granular matter is seen at the surface, and a number of fine fleecy processes having an irregular disposition*, though I can say nothing more definite concerning them.

If we now inquire as to the use of these transverse muscular prolongations so prevalent in the Nematoids, I think we shall have no difficulty in answering the question. Supposing the four sets of fibres to contract at the same time, they must necessarily tend to diminish the calibre of the cavity of the body, and so exert a compressing force upon the intestinal canal, tending to urge its contents in a definite direction according to the order of their contraction. And seeing that no muscular fibres have been detected in the intestinal canal itself, except at its two extremities, this seems to be the function which they are destined to perform.

Many anatomists have spoken of the existence of circular muscular fibres external to the longitudinal. I have not only utterly failed to recognize the existence of such, but am also quite at a loss to know what possible use they could subserve even were they present—situated as they would be on the one side within a firm chitinous cylinder, practically incapable of being contracted, and on the other external to the very strong muscular envelope formed by the great longitudinal bands.

Dr. Schneider believes the muscles of the *Trichocephali* do not conform in the type of their formation either to that of the *Colomyariæ* or the *Platymyariæ*†, though as regards the structure actually existing in *Trichocephalus dispar*, his views are at variance with those of Eberth. The latter believes that the muscles are lined internally with a layer of nucleated cells much resembling pavement epithelium, and seems disposed to doubt the organic continuity of these cells with the subjacent muscle tissue‡. Schneider, on the contrary, speaks of the muscles being covered by a homogeneous layer of fine granular substance, having numerous interspersed clear spherical spaces or "vacuoles," at the same time believing this substance to constitute an actual portion of the muscle-cells, and to be in reality but another form of the "Marksubstanz." I am inclined to think that SCHNEIDER'S description is the more correct from what I have seen in some of the free Netamoids, and more particularly so, as even EBERTH, in the same place, speaks of the resemblance of the muscles of these latter to those of the *Trichocephali.* Thus in *Symplocostoma longicollis* I have seen a similar finely granular material lying on the surface of the muscles containing in its substance what appear to be bright spherical spaces (Plate XXVIII. fig. 132), since they have no defined boundary wall*. This substance also exists in the form of a multitude of long-tailed processes extending into the cavity of the body, each of which has a similar bright space in its dilated free extremity. Whether, however, this is an independent layer of glandular substance merely lying on the muscles and differing from the ordinary "Marksubstanz," or medullary portion of the muscle-cells, I am unable to say†. I think it possibly may be so, since I have recognized the rudiments of a somewhat similar granular layer (Plate XXIII. figs. 8 & 9, *e*) on the surface of the triangular muscle-cells of *A. lumbricoides*‡. And if this is really the case, we have only to suppose the development of this substance to be extreme whilst that of the bladder portion of the cell is in abeyance, to reconcile the type of muscle-formation in the *Trichocephali*, and certain of the free species, with that of other Nematoids, since EBERTH'S observations agree with my own as to the presence of fibrous processes (Fortsätzen) in the former animals; whilst with regard to the free Nematoids, the difficulties of the investigation are such that we can only say that no such processes have yet been detected in them. The animals are too small to enable satisfactory transverse sections of the requisite tenuity to be made; neither can their bodies be slit with more ease in a longitudinal direction.

---

* Other fleecy processes having much the same appearance extend across the body, from lateral line to lateral line, diverging in their course to encircle the alimentary canal, and so suspend it in the axis of the cavity of the body (Plate XXVII. fig. 4).

† Reich. and Du Bois-Reym. Archiv, 1863, S. 20.

‡ Untersuch. über Nemat. 1863, S. 49.

NERVOUS SYSTEM.

Most various and discordant have been the statements made from time to time concerning the nervous system of the Nematoids; some mistaking for it portions of the integumentary, muscular, or even alimentary organs, whilst others have been unable to recognize any traces of such a system in these animals.

CUVIER and SERRES seemed to be of opinion that the Nematoids possessed two lateral nerves, in all probability mistaking the lateral integumental bands for these; whilst the smaller dorsal and ventral cords of a similar nature in *A. lumbricoides* have been described as nerves by OTTO[*] and CLOQUET[†]. The former also described a ventral cord in *Strongylus gigas*, giving off a few transverse branches in its course and ending at either extremity of the body in a terminal swelling. OWEN[‡] describes a somewhat similar structure in this animal, but adds that it commences and ends with slender nervous rings around the anterior portion of the œsophagus and the anus respectively. From the description given by him of this ventral cord, and the disposition of its branches, one is led strongly to believe that it in reality corresponds to the ventral median line with its attached transverse muscular processes; although SIEBOLD[§] distinctly states his belief that the ventral cord seen in *Strongylus gigas* is of a different nature from that met with in *A. lumbricoides* and other Nematoids, and adds as a description of a structure then before him, "Dans son trajet il envoie une multitude innombrable de filets latéraux, qui par leur structure intime, *différent essentiellement des faisceaux musculaires* transversaux." Professor OWEN affirms, however, that this ventral cord passes "to the left side of the vulva, and does not divide to give passage to the termination of the vagina, as CLOQUET describes the corresponding ventral cord to do in *Ascaris lumbricoides*." He agrees with OTTO in the statement that only a ventral cord exists in this animal, though BLANCHARD suggests that this may have been a mistake, owing to the destruction of the dorsal cord by the section of the body of the animal in the mid-dorsal region. BLANCHARD[||] also considers the dorsal and ventral lines to be the extremely developed peripheral portions of the nervous system in the Nematoids. He says that in all the representatives of the order he has found "une disposition tout-à-fait semblable dans l'appareil de la sensibilité," which he describes in these words:—"le corps placé dans la position où les deux nerfs principaux[¶] se trouvent être latéraux, on observe de chaque côté de l'œsophage deux très-petites masses médullaires placées exactement sur le même plan, et unie à celles du côté opposé par une double commissure extrêmement grêle, l'une passant alors au-dessus de l'œsophage et l'autre au-dessous." In the *Ascarides* and *Filariæ* these ganglia are, he says, double on each side, but in the *Sclerostomata* they become fused into one. Nothing answering to this description has been met with by other observers, and the same must be said of the double nervous cord figured and described by Professor GRANT[**] as traversing the ventral region of the body in *Ascaris lumbricoides.*

---

* I should, however, be inclined to look upon them as jelly-like masses of a transparent albuminous material rather than actual vacuoles.

† The structure which in the paper on the Guineaworm (*loc. cit.*) I described and figured as a layer of tessellated nucleated cells lying on the muscles in that region of the body compressed by the development of the genital tube, I now believe to be actual parts of the muscle-cells similar to those figured in the present memoir (Plate XXV. fig. 15), merely altered in appearance by the pressure to which they have been subjected, and actually *torn* from the surface of the muscles by the scraping process necessary for their removal.

‡ I had actually sketched such a structure before I was aware of these doubts concerning the *Trichocephali* and free Nematoids.

MEISSNER[††] described the transverse muscular processes in the *Gordiaceæ* as branches of a peripheral nervous system, and put the same interpretation upon the homologous prolongations in the *Nematoidea*; and at one time HUXLEY[‡‡] seemed inclined to assent to the same view of the nature of these transverse muscles in the Nematoids. WALTER[§§] formerly described a most elaborate system of nervous ganglia and cells with peripheral filaments in *Oxyuris ornata*, though he has since very honestly confessed the errors into which he had fallen on that occasion, and now admits to a great extent that no such system is to be met with in the animal in question.

---

[*] Magaz. d. Gesell. Nat. Fr. Berlin, vii. 1814.

[†] Sur les Vers Intestinaux, 1824, p. 23.

[‡] Cyclop. of Anat. and Phys. vol. ii. p. 130.

[§] Man. d'Anat. Comp. (Trad. Franç.) p. 126, note.

[||] Ann. des Sc. Naturelles, 3^me^ sér. 1847, p. 124.

[¶] Dorsal and ventral median lines.

[**] Outlines of Comp. Anat. p. 186, fig. 82 A.

[††] MÜLLER's Archiv.

[‡‡] Lecture in Med. Times, 1856, vol. ii. p. 384.

[§§] Zeitschr. fur Wissensch. Zoolog. 1857.

In the paper "On the Structure and Nature of the Dracunculus"[*], I myself described as belonging to the nervous system two very peculiar ganglionated cords which traverse the centre of each intermuscular lateral space. I have since repeatedly examined these structures, and although I now entertain considerable doubts about their belonging to the nervous system, I have no modifications to make in the description I then gave of their actual structure. They remain a perfect puzzle to me, and I can offer no suggestions as to their real nature.

In his recent work on 'Entozoa,' Dr. COBBOLD expresses his belief that what is now looked upon by most anatomists as an axial vessel or excretory canal in the lateral bands, should rather be relegated to the nervous system. Speaking of these structures in *Ascaris lumbricoides*, he says, "I find the lateral lines characterized by a band of large granular cells, in the centre of which lies a well-marked double-bordered canal containing fine granular matter. I cannot call the inner tube a true nervous cord, but at the same time I am willing to believe that it represents a rudimentary condition of a true nerve-system." This view is entirely unsupported by evidence, and is, moreover, directly opposed to the existing state of knowledge.

At last, after this maze of conflicting statements, we come to something more definite, and likely to bear the test of scrutiny, in the recent accurate investigations of SCHNEIDER[†] upon the nervous system of the Nematoids; the clue to which was given by the observation of LIEBERKUHN, WEDL, and himself at an earlier period, of a pale band surrounding the anterior part of the œsophagus. Bearing this in mind, and following it up at a later period by dissections conducted in the most careful manner, he succeeded in detecting in *Ascaris megalocephala* and other Nematoids what is undoubtedly the most essential portion of their nervous system.

In EBERTH'S[‡] most interesting memoir, published about the same time, upon the anatomy of both free and parasitic Nematoids, after mentioning diverse structures which might possibly be taken to represent parts of a nervous system, he evidently remains of the opinion that, so far as he has seen, there is no structure in the Nematoids that he could with confidence look upon as the representative of such a system. He appears, however, never to have carefully examined either *A. lumbricoides* or *A. megalocephala*, which are the most favourable species at present known for the detection of this structure. Up to within quite a recent period the views that I had arrived at (quite independently) accorded almost precisely with those held by EBERTH. I was far from disposed absolutely to deny the existence of a nervous system in the Nematoids, but after a pretty careful examination of many species I had utterly failed to recognize anything which I could look upon as belonging to a nervous system, and must confess felt very sceptical upon the subject. Latterly, however, I have been able to confirm the accuracy of Schneider's statements in every particular, and have no longer the shadow of a doubt that the similar structures which we have both recognized in these and other Nematoids do constitute the most important portions of a nervous system.

---

[*] Trans. of Linn. Soc. vol. xxiv. p. 111.

[†] REICH. and DU BOIS-REYM. Archiv, 1863, S. 1.

[‡] Untersuch. über Nemat. 1863.

The difficulties besetting the proper recognition of this system are, however, extreme, owing to the intimate and confusing manner in which it is mixed up with a blending of processes from the lateral and median lines, and a multitude of offshoots from the neighbouring muscles.

Schneider has detailed very fully the different parts of the nervous system as they exist in *A. megalocephala*, and as I have myself recognized them in individuals of the same species; so that I shall describe as briefly as possible what I have made out in the nearly allied species *A. lumbricoides*, and one or two other members of the same genus.

The best method for preparing the nervous system for examination in either of these animals is that recommended by Schneider, and is as follows:—Select if possible a rather young specimen, on account of the greater transparency of its tissues, cut off a portion about $\frac{1}{2}''$ in length from the anterior part of its body, and having previously settled which is the dorsal median line*, insert the point of a fine scissors within the cut extremity of the œsophagus, and then slit open this, together with the body wall, in the mid-dorsal region. The head lobes may be either cut off or left The posterior corners of the opened body wall should now be pinned out whilst the œsophagus is being carefully stripped off. The specimen should then be boiled in dilute acetic acid for about two minutes, after which the thick cuticle may generally be stripped off, and finally the preparation should be mounted in glycerine to make it still further transparent. When saturated in this fluid the preparation will bear considerable pressure without injury, and so often enable ganglion-cells and their issuing fibres to be better detected.

In *A. lumbricoides* the nervous ring (Plate XXIV.) which constitutes the most marked portion of this system is situated about $\frac{1}{20}''$ from the anterior extremity, and is about $\frac{1}{333}''$ in breadth. It merely surrounds the commencement of the œsophagus, but is not closely adherent to it, though it is almost inseparably connected with the parietes of the body. It seems to embrace the œsophagus somewhat obliquely, the dorsal portion being nearest to the anterior extremity. The method of its connexion with the body wall may be best seen in transverse sections (Plate XXVI. figs. 1 & 11), when a fibrous ring is recognized with more or less nucleated ganglion-cells interspersed, divided into four equal portions by its contact and blending with developments from the lateral and median lines. Also it is intimately connected with the four great longitudinal muscles by means of fibres passing to and blending with it in the intervals between its other attachments. These muscular prolongations passing to the nervous ring may be considered as the most anterior representatives of those processes, which throughout most of the body posterior to this situation have a transverse direction, and are attached to the median lines. No such processes exist anterior to the nervous ring, and those proceeding to it, according to SCHNEIDER, together constitute a strong sheath in which are inclosed the real nerve-fibres. According to him, what is actually seen when the band crossing the anterior part of the preparation, made in the manner stated, is examined, is this fibrous sheath, which effectually conceals the real nerve-elements within it. I quite agree with SCHNEIDER in this view; for when the flat surface of the band is examined in this manner, no ganglion-cells or unmistakeable nerve-fibres can be detected in it, though the former elements may be easily recognized in well-made transverse sections, and the real nerve-fibres, according to SCHNEIDER, may be isolated by dissecting the ring after it has been boiled in dilute nitric acid.

---

* This may always be known by its having a single head lobe opposite its termination, instead of itself terminating between two, as is the case with the ventral line.

In connexion with the ring, posteriorly, between it and the arch of the water-vascular system, are many most distinct ganglion-cells with issuing fibres, which are by no means easy of detection, since they are imbedded either in the lateral bands or amongst a web of most delicate fibres and interspersed granules, partly derived from the same lateral bands, and partly from the subjacent muscles. This is the case also with the nerves and cells anterior to the œsophageal ring. Some of the hindermost cells are, doubtless, obscured by the vascular arch, though I have never been able to ascertain that any existed posterior to this. The ganglion-cells behind the ring are arranged into four groups; two larger (*d*, *d*) occupying the substance of the lateral bands, and two smaller (*c*, *c*) diverging from a ganglionic mass in the mid-ventral region in connexion with the œsophageal ring. These ventral ganglion-cells appear to me to send a few fibres in a curved direction towards the cells in the lateral tracts, though the majority pass forwards to the œsophageal ring and median ganglion. It is from the cells in the lateral tracts that I have principally distinguished the issuing fibres; they may be distinctly seen as broad bands* directly continuous with the body of the cell, which contains a bright nucleus as well as a small quantity of fine granular matter. To ascertain the relative proportions, I measured these various parts in the cell marked *r*, and found them to be as follows:—diameter of cell $\frac{1}{588}''$, of nucleus $\frac{1}{3333}''$, and of fibre at slight distance from cell $\frac{1}{3333}''$.

In front of the œsophageal ring I could not find so many ganglion-cells existing in *Ascaris lumbricoides* as seem to be present in *A. megalocephala*, although in both species they are more abundant behind than in front of the ring. The most striking portions of the nervous system anterior to the ring are six great muscular bundles, which proceed forward to the mouth and cephalic lobes. The two bundles containing the largest number of fibres are contained in the substance of the lateral bands (*g*, *g*), *nervi laterales* of SCHNEIDER; whilst those which present the largest and most well-marked fibres are two bundles (*f*, *f*), which have been named by the same anatomist *nervi submediani*, situated on the ventral surface, on either side of the median line and about midway between it and the lateral bands; these have a serpentine course, and appear to go to the contiguous portions of the two under cephalic lobes. They seem to arise each by two principal roots, though in what precise manner could not be detected, owing to these parts being obscured by the dense fibrous meshwork which extends for some distance in front of the ring, as well as over much of the space between this and the head. The fibres composing this network are in part, undoubtedly, connecting nerve-fibres, though the greater portion of the tissue seems to be composed of mere protecting fibres, probably derived from the muscles. Near the origin of these ventral *nervi submediani*, on either side, between them and the lateral tracts, are two small but distinct bipolar ganglion-cells (*k*, *k*), one fibre of which seems to come from the œsophageal ring, whilst the other connects the cell with one of the nerves in question. The dorsal *nervi submediani* (*i*, *i*) seemed to me principally derived from the ganglion-cells in the lateral tract posterior to the œsophageal ring, and appeared to curve gently upwards to supply the upper cephalic lobe. This lobe seemed also to derive fibres from two large nucleated ganglion-cells[*], one of which is situated just external to each lateral tract (*h*, *h*), and also a small bundle of fibres from the *nervi laterales*. Although nerve-fibres have been detected only in the anterior part of the body of *A. lumbricoides* and other Nematoids, I have not the slightest doubt that peripheral branches do exist throughout the body generally; and from what I have seen of the course of one large fibre proceeding backwards from one of the lateral ganglion-cells, I suspect that they generally pass beneath the muscles to gain the deep cellular layer of the integument, in which they are principally distributed, and from which they can so easily give off filaments to the muscles or to tactile papillæ. I distinctly saw a fibre (marked *e*) leaving the substance of the lateral cord and passing beneath the muscular bundle lying outside it. Dr. SCHNEIDER seems inclined to think that some large nerve-fibres may pass posteriorly in the substance of the dorsal and ventral median lines, though he has never absolutely traced nerve-fibres passing from the central ring into these bodies. He rests his opinion upon the fact that in fine transverse sections which he has made of the median lines, he has found them perforated lengthwise by cavities having an elliptical or oval cross section; which tubes or cavities, he states, are invariably filled with a transparent, homogeneous substance of a reddish or yellowish tint. He says that from six to eight such bodies can be detected in the ventral median line of *A. megalocephala*, but only from four to six in the dorsal. These are considered to be transverse sections of nerve-fibres; but the fact that they have a distinctly larger diameter than the principal nerve-fibres issuing from the ganglion-cells seems to me strongly opposed to this view. I have myself been unable to recognize such structures in the median lines, so must refer for further details concerning them to Dr. SCHNEIDER's important memoir.

---

* According to SCHNEIDER, in transverse section they present a flattened oval appearance.

The nervous system of *Oxyuris curvula* has also been carefully examined by SCHNEIDER, and in this animal he has found the œsophageal band most distinct, as well as the anterior fibres, though very few ganglion-cells could be detected. He has with difficulty, moreover, detected the most important parts of this nervous system in *Strongylus*

---

[*] These large cells have rather a remarkable appearance from their isolated position, but still the aspect of their nucleus and cell-contents corresponds most closely with that of other ganglion-cells.

armatus. I have also detected the œsophageal band and ganglion-cells in *Ascaris marginata*, *A. osculata*, *A. spiculigera*, *A. mystax*, and *Dracunculus medinensis*, and have seen, from the exterior only, what seemed undoubtedly the œsophageal band in *Strongylus filaria* and *Cucullanus heterochrous.*

LEUCKART has described a pale nervous band containing ganglion-cells surrounding the œsophagus, close behind the mouth, in *Oxyuris vermicularis*, and has also described [*] what he considers to be a nervous ring, occupying a similar situation, in *Trichocephalus hominis* and *Trichina spiralis.* EBERTH [†] has likewise seen a structure of the same kind in several *Trichocephali* and *Trichosomata*, though he seems very unwilling to look upon it as constituting part of a nervous system.

As to the peculiar, bright, homogeneous-looking ring surrounding the œsophagus in some parasitic Nematoids, such as EBERTH has figured [‡] in *Spiroptera megastoma* and *Sclerostomum dentatum*, there can, I think, be little doubt that this is homologous with the similar body surrounding the œsophagus of so many of the larger marine Nematoids, and concerning which both EBERTH and myself have already expressed our opinions that it does not belong in any way to the nervous system. It differs altogether from the nervous œsophageal band now distinctly recognized in so many Nematoids, not only by its position, which is often far removed from the mouth, but also by its structure and disposition. No fibres can be recognized in its tissue, it is considerably larger and thicker in size, and, in addition, seems to be connected more intimately with the œsophagus itself than with the parietes of the body.

Notwithstanding the existence of well-developed ocelli in many species of free Nematoids, both EBERTH and myself have been quite unable to detect any nerve-filaments in connexion with them, or in fact any certain evidence of the presence of a nervous system in these animals. That such a system does exist I have not the smallest doubt; and considering the difficulties besetting its recognition even in large species of parasitic Nematoids, I think that our failure hitherto in demonstrating its existence in these comparatively minute animals is after all, notwithstanding their transparency, no very great cause for wonder.

I have lately, in examining some of these animals with a $\frac{1}{25}''$ object-glass, detected some almost invisible fibres surrounding the œsophagus. I have recognized them distinctly in *Monhystera stagnalis* and in *Plectus parietinus.* In this last species they are situated, too, just anterior to the orifice of the ventral gland. I think it very probable that this may be its nervous œsophageal band, but cannot speak more positively on the subject.

---

[*] Bericht über der Leistungen in der Naturgeschichte der niederen Thiere für 1859, und Untersuch. über *Trich. spiralis*, S. 48.

[†] Untersuch. über Nemat. S. 51.

[‡] *Loc. cit.* Taf. ix.

ORGANS OF SENSE.

The bodies most unmistakeably coming under this denomination in the Nematoids are the ocelli so frequently met with in the free species, and of these, almost exclusively in the marine types. As yet I have only encountered a structure of this kind in one land or freshwater species, namely, *Monhystera vulgaris*. As a rule these bodies are somewhat conical aggregations of reddish-coloured pigment-granules, generally two in number, situated on the dorsal surface of the anterior part of the œsophagus, and exhibiting no refracting portion answering to a cornea or lens, though different species may be found to deviate from every one of these common characters, some in one respect and some in another*. Thus in EBERTH's *Enoplus cæruleus* they are of a blue colour; in the genus *Enchelidium* there is generally one very large pigment-heap almost surrounding the œsophagus, of a brownish colour, in the front of which are three or four clear lentil-shaped bodies or lenses; in *Phanoderma* the pigment-heaps are well-marked, lateral, conical aggregations of bright vermilion-coloured pigment. Where present, in the genus *Cyatholaimus* they are irregular quadrate masses of a brownish-red colour, whilst in the freshwater species above mentioned there is only one small bright-red mass on the dorsum of the œsophagus. In the genus *Leptosomatum* there are two conical masses of red pigment on the dorsum of the œsophagus, each having a single lentil imbedded anteriorly (Plate XXVII. fig. 33). In all the cases just mentioned the pigment appears to be situated externally to the sheath of the œsophagus; but in the genus *Enoplus*, and in two or three species of *Oncholaimus*, there seems to be an increased aggregation of pigment-granules into ocelli-like masses in the cervical region of the animal, these aggregations being situated beneath the bounding membrane of the œsophagus, within its walls, and being constituted of the same kind of pigment-granules that may be found scattered more sparingly throughout the rest of the œsophagus. These internal pigment-heaps I propose to call *pseud-ocelli*; they are, doubtless, the early foreshadowings of the more perfect organs; and accordingly, in one species of the genus *Enoplus* (*E. inermis*), I have not found the rudimentary organs similar to those existing in most other species, but what appear to be two distinct pigment-heaps on the external surface of the œsophagus—this organ itself being almost free from scattered pigment-granules. The ocelli are very inconstant organs; they seem present or absent in the same genus according to the requirements of the different species; thus, in some species of *Cyatholaimus* living in marine mud they are absent, whilst they are present in other members of the same genus tenanting the smaller weeds of tide pools.

As before stated no nerve-filaments have ever been actually traced in communication with these ocelli.

The so-called copulatory papillæ in the ventral region of male *Ascarides* and many other kinds of Nematoids, are I believe principally tactile organs, and I have little doubt that the four papillæ on the cephalic lobes of the *Ascarides* are also sense-organs of some sort, either simply tactile in their nature, or perchance endowed with the faculty of recognizing qualities in bodies different from those which we are capable of appreciating by any of our five senses. No nerve-filaments have yet been traced to either kind of papillæ, and whether or not they have any suctorial properties seems a matter of uncertainty. Concerning what SCHNEIDER has termed the "cervical and caudal papillæ" in the lateral regions of the body, I have already spoken. It seems to me by no means unlikely that the head-lobes themselves in the *Ascarides* are principally tactile appendages, a very large quantity of nerve-fibres pass into them, and in their substance they show a reticulated network of fibres of some kind (Plate XXIV. *l*, *l*, *m*), which I suspect are in great part nervous.

---

* Illustrations of these various modifications of the ocelli may be found in EBERTH's 'Untersuch. über Nemat.,' and also in my "Monograph on the *Anguillulidæ*," Trans. of Linn. Soc. vol. xxv.

ORGANS OF DIGESTION.

The alimentary canal in the Nematoids is usually a simple, unconvoluted tube, extending through the body in the parasitic species from the terminal mouth to an anus also terminal, or situated but a very short distance from the posterior extremity of the body. In many of the free Nematoids, however, the posterior extremity of the body extends for a considerable distance behind the anus. This tube is always divisible into two distinct portions, an anterior œsophageal part (separated from the next by a constriction), which may be either simple or provided with one or more swellings in its course, and having walls either strongly muscular or for the most part cellular; and a posterior part or intestine proper, with no appreciable muscular tissue in its walls, but always having a more or less developed cellular sheath, performing probably an hepatic function. The length of the œsophagus, as compared with that of the body of the animal, varies much in different species, though as a general rule it is proportionally longer in the free than in the parasitic species. In the former it frequently occupies one-sixth or one-fifth of the whole length of the body, and in *Sphærolaimus hirsutus* as much as one-third, whilst in the parasitic species it frequently does not occupy more than from $\frac{1}{20}$ to $\frac{1}{30}$ of the length of the body, and in many species of *Filaria* even less than this. There are exceptions, however, to this rule met with in the genera *Trichocephalus* and *Trichosoma*, which are most notable for the length of the œsophageal portion of the body; in this respect, as well as in the structure of their œsophagus and many other points in their anatomy, these animals show decided affinities to the free Nematoids, although in some other respects they are widely different.

The *oral opening* in the Nematoids seems most frequently to be triradiate, as it is in the members of the genus *Ascaris*, though in some species of the parasitic and in many of the free animals it appears to be circular. So far as I have seen, it is always terminal and situated in the centre of the anterior extremity.

A *pharyngeal cavity* is rather the exception than the rule, though it exists to a well-marked degree amongst the parasitic Nematoids in the genera *Cucullanus*, *Sclerostomum*, *Angiostoma*, *Syngamus*, and *Anchylostoma*, whilst it is long and cylindrical in *Dispharagus*, and rudimentary in the genera *Heterakis*, *Stenodes*, *Stenurus*, *Spiroptera*, and *Strongylus*. In all, this cavity is lined with more or less strong chitinous walls, more developed in some situations than in others, so as to form horny plates or even tooth-like projections. The horny plates may be well seen in the members of the genus *Cucullanus*. In *Anchylostoma duodenale*, according to KÜCHENMEISTER, there are four strong teeth projecting from the upper wall of the pharynx, whilst SIEBOLD describes the entrance to the pharyngeal cavity in *Strongylus armatus*, *S. hypostomus*, *S. dentatus*, and *S. tetracanthus* as "garnie d'un cercle de dents cornées," and adds, "il existe des muscles spéciaux pour les mettre en mouvement." Amongst the free Nematoids*, the most distinct pharyngeal cavities with horny capsules exist in the genera *Mononchus* and *Oncholaimus*, the former having one tooth-like projection and the latter three; it is rather long and cylindrical in *Rhabditis*, somewhat pear-shaped in *Sphærolaimus*, cup-shaped with horny projections from its base in *Diplogaster*, and exists with more flexuous walls in the genera *Linhomœus*, *Cyatholaimus*, *Spilophora*, and *Chromadora*. In the last two genera three horny apophyses extend backwards from the pharyngeal cavity, which are extremely well developed in *Spilophora robusta*. In the genus *Enoplus* three well-marked and separate teeth exist in the pharyngeal region, though I have never been able to make out their exact relationship to the commencement of the alimentary canal. In the genus *Dorylaimus* the pharynx is modified into a strong hollow spear-like body, and can be protruded for some distance from the mouth by means of special muscles (Plate XXVIII. fig. 3) which move it in common with the anterior part of the œsophagus. In all immature species of this genus, a reserve spear exists in the substance of the œsophagus a short distance behind, and of a slightly larger size than the one *in situ*, whose place it subsequently takes. I shall refer to this subject again in the section on development. In the genera *Aphelenchus* and *Tylenchus* a spear-shaped horny pharynx also exists, simple in the former, but having a trilobed base in the latter, though in neither of them is there present the reserve spear met with in the *Dorylaimi*. Most likely these spears are exsertile also, though I cannot speak from actual observation; they suggest a resemblance to the "sharply-pointed dentule"†, capable of being exserted from the mouth in some species of the genus *Mermis*, whilst what is met with in the *Dorylaimi* recalls the principal and reserve proboscideal spines in the members of the genus *Tetrastemma*‡ and other of the *Nemertidæ*.

In those species in which no pharyngeal cavity exists, the mouth communicates at once with the *œsophagus*. Besides innumerable variations in detail, two principal modifications in the nature of this portion of the alimentary canal are met with in the Nematoids, inasmuch as in nearly all the parasitic forms, and in about one-half of the free species, it has a well-developed muscular structure, whilst in the genera *Trichina*, *Tri-*

---

* The different modifications now to be mentioned are figured, and described more fully in the "Monograph on the *Anguillulidæ*," Trans. of Linn. Soc. vol. xxv.

† COBBOLD, Entozoa, 1864, p. 61.

‡ CARUS, Icon. Zootom. tab. viii. 10.

chocephalus, and *Trichosoma* amongst the parasitic, and the remainder of the free Nematoids, its walls are more or less distinctly cellular, and no muscular fibres can be detected.

The *Ascarides* afford good examples of the simple muscular* œsophagus met with in so many Nematoids, and its structure may at once be recognized by the examination of their transverse sections (Plate XXV. fig. 3). We see then a circular section having a thin structureless bounding wall, whilst internally there is a narrow triradiate cavity bounded by a strong chitinous membrane, between which and the external walls are seen on all sides a series of radiating close-set muscular fibres. By the simultaneous contraction of these the narrow triradiate passage would be converted into a wide triangular canal. If the plains of the radii were prolonged they would be found to alternate in position with the cephalic lobes, one pointing to the mid-ventral region, and the two others upwards and outwards in opposite directions. In certain Nematoids an appearance of longitudinal bands is seen along the axis of the œsophagus. This is met with in the genus *Cucullanus*, and a transverse section (Plate XXVII. fig. 13, *d*) at once reveals their nature, showing them to be produced by six thickenings of the internal chitinous lining of the œsophagus. Similar formations exist among the free Nematoids, and are most marked in *Sphærolaimus hirsutus*. Two or three species of the genus *Ascaris* exhibit a cæcal prolongation of the œsophagus, extending backwards for a short distance along the side of the intestine; this I have seen in the so-called *Filaria piscium*† of the Haddock, and in *Ascaris spiculigera*, and it exists in other species. In these two animals also a cæcal prolongation of the intestine extends forwards (Plate XXII. fig. 9 *a* & *b*), whilst in *A. osculata* the intestinal prolongation alone is present. Nothing definite can be said concerning their use. In the genus *Trilobus*, amongst the free Nematoids, the three lobe-like prolongations at the termination of the œsophagus seem to be developments of much the same nature, and so also, in all probability, are the four glandular bodies in the same region spoken of by De Quatrefages as existing in his genus *Hemipsilus*. The solid, though bright and almost homogeneous ring surrounding the œsophagus in many of the free and some of the parasitic species has already been mentioned in speaking of the nervous system. Amongst the free Nematoids it is very well marked in the members of some of the marine genera, such as *Leptosomatum* (Plate XXVIII. fig. 33, *b*), *Phanoderma*, *Symplocostoma*, and *Oncholaimus*. What its real nature may be is quite problematical both to Eberth and myself. It may be glandular, but no positive statement can be made, save that it does not appear to belong to the nervous system. In the land and freshwater species it seems absent altogether, and the same is the case with a large proportion of the marine forms. Many Nematoids having a muscular œsophagus present one or more swellings in its course. As a rule this swelling, when it exists, is terminal, though in some species another may be present near the middle of the œsophagus, or one in this situation may be the only swelling met with. These enlargements, again, may be either simple developments of the muscular walls, or in addition they may contain in their interior a more or less complex apparatus of horny chitinous plates. The simple terminal swelling may be seen amongst the free Nematoids in the genus *Spira*, whilst horny plates of gradually increasing complexity are seen in the genera *Aphelenchus*, *Cephalobus*, *Anguillula*, *Rhabditis*, and *Plectus*, and to continue the series amongst the parasitic species, in *Heterakis*, *Oxyuris*, and many others. In *Rhabditis* there is in addition a simple, central, elongated swelling, whilst a somewhat globular enlargement exists in this region only in the genera *Tylenchus* and *Diplogaster**.

---

* Although Professor Owen in his 'Lect. on Comp. Anat.' 1855, p. 104, alludes without *dissent* to the opinion expressed by Cloquet, that "the thickened *glandular* parietes of the œsophagus in the *Ascaris lumbricoides* may provide a secretion analogous to that of salivary organs."

† This animal, as it exists in the Haddock, at all events is a young *Ascaris*; reasons for this statement will be advanced further on in the section on development.

The terminal developments have generally been named and described as stomachs, the internal horny plates being looked upon as a kind of teeth, but, as I have on a former occasion pointed out, there seems little warrant for this belief. No dilatations of the central cavity of the organ are met with in these situations, merely an hypertrophied condition of the muscular walls, and the horny plates, instead of being called "tooth-like, crushing organs"†, should, I think, be considered as rather valvular in their nature; the whole apparatus being principally destined to facilitate the taking of food, though partly, perhaps, also more effectually to prevent the regurgitation of the intestinal contents during the movements of the animal. The Nematoids have no prehensile organs of any kind, and their food is, I believe, principally taken by a process of suction. The simultaneous or successive contraction of the transverse radiating fibres, throughout the length of the œsophagus, producing a dilatation of its central canal would cause an inrush of any food or fluid matter to which the mouth might be applied. I have often seen the passage of fluid along the œsophagus of the free Nematoids in this way; the muscles contract with the greatest rapidity, and in *Rhabditis marina* I have seen the valvular plates open and shut just as quickly to give passage to the fluid. Whether the tooth-like projections from the pharyngeal cavity in the *Oncholaimi* are capable of movement I cannot say; I, at least, have never seen them move, and they appear closely adherent to the walls of their enclosing cavity. In *Tylenchus* and *Aphelenchus* the lumen of the œsophagus is very narrow, and apparently stiff and cord-like in external appearance. This misled DAVAINE, so that he did not recognize its real nature in *Tylenchus tritici*, but spoke of it as "un filament simple, tres distinct, semblable à une fibre de tissu élastique" proceeding from the stylet, and whose object he thought was "de donner de la force et de la résistance à l'extrémité antérieure de l'animal"‡.

The best examples of the cellular or glandular structure of the œsophagus are met with in the genera *Trichosoma* and *Trichocephalus*, and in *Trichina spiralis*, though I am unable to agree with EBERTH with regard to some of the details of their anatomy. The first portion of the œsophagus behind the mouth, in these animals, is different from the remainder, it is narrow, and seems to have granular rather than cellular contents.

---

* See "Monograph on the Anguillulidæ" for figures.

† COBBOLD, Entozoa, p. 367.

‡ Recherches sur l'Anguillule du blé niellé, 1857, p. 24.

It has been named by LEUCKART "mouth intestine" (Munddarm). Throughout the rest of its extent, so far as I can understand EBERTH'S description*, he says the œsophagus is enclosed by a cellular organ which surrounds it on three sides, as an incomplete channel, leaving only the ventral surface free, and he looks upon this organ as a special glandular body, though unfortunately he says nothing further with regard to the actual structure of the œsophagus within the cellular development. I do not know what LEUCKART'S views upon the subject are, but to me it appears almost certain that, although more or less constricted at intervals, the œsophagus in all these animals may be considered a cylindrical organ with a central axial lumen, the ordinary transverse radiating muscular fibres being almost wholly replaced by large nucleated cells with granular contents (Plate XXVII. figs. 18 & 19). Whether muscular fibres exist or not seems very doubtful; I have never seen any, neither does EBERTH speak of their presence. The section of the lumen in *Trichocephalus affinis* seemed to me to have a somewhat triangular form. In *Trichosoma longicolle* all the posterior portion of the œsophagus is divided into elongated compartments by constrictions at intervals (Plate XXVII. fig. 14). Near the centre of each compartment there appears a clear spherical mass with no very defined bounding wall, whilst along the crenated margins a series of similar though much smaller bodies exist, which are in all probability nucleoli enclosed within an outer cell-wall, as are the similar bodies met with in the œsophagus of *Trichocephalus affinis* (Plate XXVII. fig. 19). In this latter animal the rounded or crenated borders are still better marked, and the cellular body with its enclosed spot seen opposite each crenation, are in all probability the nucleus and nucleolus of a still larger granule-containing cell whose walls are indistinct. In a very thin section which I succeeded in making of this animal at about the termination of the anterior third of the œsophagus, this organ was seen to fill almost the whole width of the cavity of the body (Plate XXVII. fig. 18), and to be made up entirely of an aggregation of nucleated cells, each densely filled with granules, surrounding the small somewhat triangular central lumen. I need not describe here the processes of a somewhat triangular shape, passing from the parietal muscles of the body to the constricted portions of the œsophagus, which are met with throughout a great part of its length, and act as a series of mesenteric processes, since most observers are agreed as to their presence and nature. In the *Trichocephalus affinis*, although no demarcation of the œsophagus into large segments exists similar to what I have described in *Trichosoma longicolle*, yet there do exist large cellular bodies at pretty regular intervals, which seem homologous with the clear non-granular mass present within each segment of the œsophagus in the latter animal. Their structure is, however, different, since in *T. affinis* it consists of a clear cell with no defined contents, save an excentric granular nucleus with its contained nucleolus. These are very well marked towards the posterior extremity of the œsophagus. In the *Trichocephali* and *Trichosomata*, generally on either side of the termination of the œsophagus, there is a pear-shaped or more elongated prolongation directed forwards, such as I have represented in Plate XXVII. fig. 14, *c*. It is often of a yellowish colour, and sometimes no nucleus can be detected. KÜCHENMEISTER mentions these bodies in his description of *Trichocephalus dispar*, and EBERTH says he has found them in every species examined. For further details concerning the œsophagus and other parts of the animals included in this division of the Nematoids, I must refer to Dr EBERTH'S most interesting memoir and beautifully executed figures.

---

* Untersuch. über Nemat. p. 50.

Amongst the free Nematoids there are a large proportion of the species which do not present a well-marked muscular œsophagus, and among them the best examples I can cite are the members of the genera *Phanoderma*, *Leptosomatum*, *Enoplus*, *Oncholaimus*, *Chromadora*, and *Dorylaimus*. I might name several other genera, but those just given contain species of the largest kind, and are therefore best fitted for examination. In the first five genera, which are marine, a quantity of pigment-granules are generally present, more or less thickly interspersed in the substance of the œsophageal walls, and by means of a rather thick section of the œsophageal region of the body of an *Enoplus communis* I was enabled to ascertain that the œsophagus itself was cylindrical, and had the characteristic triradiate lumen in its centre, and that moreover the olive-coloured pigment was principally arranged along three longitudinal lines, corresponding closely in position with the apices of these three radii. What, however, the exact histological structure of the œsophageal walls may be I am unable to say; in the genera above mentioned it certainly presents no well-marked granular cells, such as have been described in the *Trichocephali* and allied animals. EBERTH[*] also seems to have been much puzzled by the structure of the œsophagus in some of these animals, and is able to throw but little light upon the subject. In *Phanoderma Cocksi* and other members of the same genus, there are three longitudinal rows of bright orange-coloured pigment-granules, and the posterior widening half of the œsophagus is constricted at pretty regular intervals, so as to give its borders a crenated appearance, very much resembling what we find in *Trichina spiralis* and the *Trichocephali*. From the cut extremity of the œsophagus in *Dorylaimus stagnalis* I have seen a number of small hyaline cells of varying size (Plate XXVII. fig. 5) issue, but with this exception have never been able to detect well-marked cells in the œsophageal walls of any of the free Nematoids. All that I have been able to make out was a kind of clear, gelatinous, undifferentiated tissue containing in its substance large, interspersed, pigment-granules. It is possible that this substance may be a kind of contractile sarcode—at all events it seemed very consistent and somewhat elastic. In the various species of the genus *Enoplus* a number of bright lines or linear spaces exist, having a transverse direction, though what the exact nature of these structures may be I have been unable to ascertain. These cross stripings have also attracted the attention of EBERTH and BERLIN[†].

Judging from what I observed formerly of the structure of the œsophagus in the Guineaworm, I should imagine that it must have been originally an organ with cellular parietes, the disintegration of which would account for the quantity of granular matter contained within its sheath, and the isolated condition of what should have been its axial lumen or canal. In this animal, lining the inner side of the sheath of the œsophagus, was a longitudinal layer of fibres apparently muscular[*] in their nature. This is the only Nematoid in which such fibres have yet been recognized.

---

[*] Untersuch. über Nemat. 1863, p. 9.

[†] MÜLLER'S Archiv, 1853.

The remaining or *intestinal* portion of the alimentary canal is subject to much less variation, and its essential structure is the same in all Nematoids. It is separated by a well-marked constriction, as well as by a difference of tissue, from the œsophagus, being composed of an external structureless membrane, bounded internally by a more or less developed layer of cells, each of which contains a clear nucleus-like body and a number of dark spherical particles[†]. The nucleus very frequently appears to be absent, though this may be owing to its being obscured by the pigmentary particles; and where present it often appears only as a clear space free from granules (Plate XXVIII. figs. 6, 10, & 29). Internally the cells are bounded by a kind of structureless cuticle, which perhaps is not an independent formation, but is produced by a thickening of the walls of the cells next the central cavity. In *Ascaris lumbricoides* and many other species of the same genus, these intestinal cells are long and columnar, and when an isolated portion of intestine is spread out and examined through its outer membrane, the hexagonal bases of these cells may be seen, presenting a regular tessellated appearance (Plate XXIII. figs. 10 & 11). These cells are very long in *A. megalocephala* and *A. mystax*, and in this last animal the internal cuticle is very thick and well developed (Plate XXVI. fig. 5). The cuticle is distinct also in *A. osculata*, whilst in many of the free Nematoids it forms an inner tube quite distinct, and capable of being isolated from the outer and the intervening cellular layer; this may be well seen in the members of the genera *Tylenchus*, *Aphelenchus*, and *Monhystera* (Plate XXVIII. fig. 28). In *A. osculata*, as well as in *A. spiculigera* and *Filaria piscium* from the Haddock, I have found the cavity of the intestine almost obliterated by the great development of the cellular layer, and its projection inwards in the form of large rounded masses (Plate XXVI. fig. 10); some of the cells composing them are elongated, though for the most part they have a rounded form. I have seen similar nodosities of the cellular layer at the posterior part of the intestine in *A. megalocephala*. In several *Strongyli* that I have examined I have found the intestinal granules very large and somewhat light coloured, though I have not been able to detect the separate cells in which the granules are contained, and the same difficulty occurs with many other Nematoids. This cellular or glandular layer is described by DUJARDIN as being "d'un rouge vif" colour in *Filaria labiata*, though in other animals it seems to vary from a whitish to an almost black colour, the predominant tint being olive-brown. In some species the cells are of a rounded shape, and this, allowing for alterations by mutual pressure, seems generally to be the form in the free Nematoids, together with the *Trichocephali* and their allies. In these animals the separate cells are often most distinct, and with their fellows produce a well-marked tessellated appearance, though in others the boundaries of the several cells cannot be recognized, and an intestinal sheath of thickly disposed granules is all that can be detected. The separate cells are very small in *Enoplus Dujardinii*, and very large in *Monhystera ambigua* and *M. disjuncta**, whilst they appeared almost absent, or at least free from granules, in *Spilophora costata*, and in some specimens of *Leptosomatum elongatum*. In *Symplocostoma longicolle* the arrangement of the cellular layer in old specimens is often most irregular.

---

[*] Trans. of Linn. Soc. vol. xxiv. p. 116.

[†] These particles, when liberated by rupture of the cells, generally exhibit an active molecular movement; I have often watched for evidences of this movement in the unruptured cells, but have always failed except on one occasion, and then I witnessed a most active molecular movement within the cells of a portion of intestine which had been expressed from the cavity of the body of one of the freshwater species of the free Nematoids.

According to EBERTH a well-marked cuticle exists bounding the cells internally in *Sclerostomum dentatum*, as well as in *Strongylus commutatus* and *S. tenuis*; whilst in the *Trichocephali* he says he has seen this, after the application of water, appear to be composed of a closely-packed row of little rod-like bodies. He further says that towards the end of the intestinal canal of the latter animals, he has recognized transverse muscular fibres in the larger species.

The terminal portion of the intestine, which some have named the rectum, loses the cellular layer, contracts in calibre, and appears for some distance to be encircled externally by muscular fibres, which probably have a sphinteric function (Plate XXV. figs. 5, *b*), and with which, also, certain other muscular fasciculi, passing to the walls of the body and having a dilating function, are connected. The structureless walls of the rectum are continuous at the transverse anal cleft with the chitinous integument, so that we may perhaps consider the structureless bounding membrane of the intestine to be a modification of this tissue.

Hitherto many doubts have been entertained as to whether or not an anal orifice existed in the Guineaworm (*Dracunculus medinensis*), and in my paper on the anatomy of that animal, I stated that I had traced the intestinal canal to what appeared to be its termination close to the posterior extremity of the animal, in the centre of the great ventral, longitudinal muscular band—corresponding pretty closely in situation to the place where RUDOLF WAGNER stated that he had seen an actual aperture through the integument. I have lately examined other well-preserved specimens of this animal, and have succeeded in detecting a minute aperture through the integument opposite the position to which I again traced the termination of the intestine internally (Plate XXVII. fig. 20, *a*). This aperture is, however, altogether abortive, and by no means proportionate in size to that met with in other Nematoids. Indeed the development of the intestinal canal as a whole appears by no means to have kept pace with the development of other parts of the body. The termination of the alimentary canal is fixed in position by fibres passing to it from the lateral intermuscular spaces of the animal. In the embryos of one of these other specimens of *Dracunculus* that I have lately examined, which seemed to be in a more developed condition than any I had before met with, I distinctly found the intestine provided with an anal aperture slightly anterior to the level of the lateral sacculi (Plate XXVII. fig. 22), in much the same position as it was represented to exist by CARTER*.

---

* Trans. of Linn. Soc. vol. xxv. pls. ix. & xii.

In the Nematoids generally, the intestine is bound to the parietes of the body by more or less developed retinacula, which are usually delicate prolongations from the longitudinal muscles.

The cellular layer lining the intestine has in all probability a glandular function to perform, and its share in the process of assimilation may perhaps entitle it to be looked upon as possessing a rudimentary *hepatic* function. Such seems to be the general opinion as to its nature.

With regard to the food of the parasitic Nematoids, a great difference exists according to the particular parts of the body of their respective hosts which they are in the habit of frequenting, and it seems reasonable to expect that differences in organization might be met with amongst these species, in a measure coincident with the degree of elaboration of the fluids upon which the respective animals feed. We seem to be able to recognize this to a certain extent, since in *Prosthecosacter inflexus*, inhabiting the heart and vascular sinuses of the Porpoise, and consequently drawing its nourishment from a fluid already much elaborated, I have found a low development of the glandular structures of the body; whilst in the *Ascarides*, such as *A. spiculigera* from the stomach of a Cormorant, or *A. osculata* from the intestines of the Seal, feeding upon less elaborated materials, we have seen the enormous development of the glandular hepatic lining of the intestine; and in *A. lumbricoides* we meet with an enormous development of the glandular portions of the muscles in the form of bladder-like prolongations, constituting the "appendices nourriciers" of CLOQUET.

In the "Monograph on the Anguillulidæ"†, I have mentioned a few particulars concerning the food of the free Nematoids, and have also alluded to the occasional large quantity of fat met with within the alimentary canal of these animals, apparently as a primary product in the process of assimilation.

GLANDULAR SYSTEM.

The glandular system, under various forms, is extremely well developed in the Nematoids, and seems to fulfil a most important function in their economy.

A series of floating gland-cells exists in variable quantities suspended in the fluid contents of the general cavity of the body, which may be considered analogous at least to the blood-cells or corpuscles of higher animals. The fluid in which they float is mostly colourless, though in some Nematoids, as in *Syngamus trachealis*, it is of a blood-red colour. The cells themselves vary much in size as well as in number. In *Ascaris lumbricoides* they may be found in the fresh dead animal aggregated together in minute masses in the cavity of the body, the cells themselves being about $\frac{1}{3500}''$ in diameter and of a somewhat light-olive colour (Plate XXIII. fig. 12). In many of the free

---

* Annals of Nat. Hist. Ser. 3, vol. iv. (1859) pl. 1, fig. 6.

† *Loc. cit.* p. 84.

Nematoids these cells seem to be almost absent, or are so small as scarcely to deserve any other appellation than granules, whilst in others they are larger and more abundant. Unusually large bodies of this nature, with a distinct nucleus, are frequently seen within specimens of *Leptosomatum figuratum* (Plate XXVII. fig. 31).

The cellular or medullary portion of the muscle-cells which have been before described, may, in all probability, be justly considered as glandular elements; and under this head I should include the structures previously mentioned as existing in connexion with the muscles of *Symplocostoma longicolle*, and which are apparently homologous with the cellular structures so abundantly met with in many of the other free Nematoids. These glandular formations on the surface of the muscle are generally most marked at the anterior and posterior extremities of the body, and seem to attain their maximum development, so far as I have seen, in the various species of the genera *Leptosomatum* and *Phanoderma*.

The glandular nature of the cellular mass lining the intestine has just been spoken of in the concluding portion of the last section.

Professor Owen* has described structures which he considers to be analogous to salivary organs, "consisting of four small slender blind tubes, each about two lines in length, which are placed at equal distances around the commencement of the alimentary canal in the *Gnathostoma spinigerum*, a small Nematoid worm closely allied to *Strongylus*," which he discovered in the tunics of the stomach of a tiger. These tubes he seemed to think emptied their secretion into the mouth. Eberth has described and figured two small glandular bodies in connexion with the large pharyngeal cavity of *Enoplus cæruleus*. Each of these is rather elongated in form and provided with a nucleus, and he thinks may open into the pharynx anteriorly.

Glandular bodies are present in connexion with the termination of the intestine in many Nematoids, both free and parasitic. These have been carefully described and figured by Eberth in many species, and though, curiously enough, he seems quite to have made up his mind as to their nature when existing in the free Nematoids, by the fact of his having given them the name of "anal glands," still when he meets with similar structures in the parasitic species he seems to dally with the idea that they may perchance belong to the nervous system, seemingly led away in this manner by the misconceptions into which Walter had fallen concerning the nervous system of *Oxyuris ornata*, an animal in which anal glands appear to be present. These structures Walter still persists in believing should be considered as central ganglia of a nervous system.

I have met with these anal glands amongst the free Nematoids in the genera *Anticoma*, *Linhomœus*, and *Cyatholaimus*. They consist of from two to four finely granular masses, varying in shape and size, each having a clear central nucleus-like body, which may when small, as in the genus *Anticoma*, be in close connexion with the rectal portion of the intestine, or if larger may occupy much of the cavity of the body between this and the posterior extremity. Eberth has also figured these bodies, but we have neither of us been able to ascertain what are their exact connexions, or whether they are provided with excretory canals. I have seen similar structures in two or three species of *Strongyli* and in *Heterakis acuminata*, whilst they have also been met with, as well as figured, by EBERTH, in *Oxyuris ambigua* and *Heterakis vesicularis*. In these various parasitic species their number and arrangement is different, though their essential nature is the same; they present the appearance of granular nucleated bodies variously arranged around the termination of the intestine, and connected with it by pedicles, which very probably are excretory ducts.

---

* Lect. on Comp. Anat. of Invert. 2nd Ed. 1855, p. 103.

Another description of gland exists in connexion with the vagina in the females of certain species of free Nematoids, which have been called "vaginal glands." In histological structure and appearance they are very similar to the anal glands just described. They are stalked, often pyriform in shape, having finely granular contents, and may or may not show the same bright central body or nucleus. They are connected with the vagina close to its external aperture. EBERTH has discovered four such bodies in his *Enoplus tuberculatus*[*], and two in his *Enoplus gracilis*, whilst in *Enoplus megopthalmus*, where he has also met with them, they present a different character, and consist of two pear-shaped masses seemingly composed of an aggregation of nuclei[†]. I have met with two equal, stalked, pear-shaped glands in *Symplocostoma vivipara*, one anterior and the other posterior; a similar position of two unequal glands in *Tachyhodites velox*; and one large posterior gland only in *Sphærolaimus hirsutus*[‡].

I am aware of only one species of parasitic Nematoid in which such organs are to be met with, and this is in *Heterakis vesicularis*, in which EBERTH has represented[§] three stalked, pear-shaped, glandular bodies in connexion with the anterior wall of the vagina[||].

---

[*] Really *Phanoderma tuberculatum*.

[†] Unters. über Nemat. Taf. ii. 24.

[‡] For figures see 'Monograph on Anguillulidæ.'

[§] Würzb. Naturwissensch. Zeitsch. 1860, Erst. Bd. Taf. iii. 21.

[||] Before dismissing the subject of the glandular and secretory organs of these animals, this seems a suitable place for me to record some of the remarkable effects invariably produced upon myself whilst working at the anatomy of *Ascaris megalocephala* from the Horse. Emanations from this animal had the most decided and poisonous influence upon me, and this not only when the animal was in the fresh state, but after it had been preserved in methylated spirit for two years, and even then macerated in a solution of chloride of lime for several hours before it was submitted to examination. I first examined this species in the spring of 1863, when certain strange effects were produced which I was enabled to trace absolutely to the fact of my working with this animal. These were a greatly increased secretion from the Schneiderian membrane, with irritation of it, causing continuous sneezing, also irritation of the conjunctiva, with such a sense of itching about the eyelids and caruncula lachrymalis as to make it extremely difficult to abstain from rubbing them. When they were rubbed this immediately gave rise to a swollen and puffed condition of the eyelids, swelling of the caruncula, and extreme vascular injection of the conjunctiva, and if the rubbing was at all persisted in, actual effusion of fluid would take place under the conjunctiva, raising it from the subjacent sclerotic and cornea. A few minutes would suffice to produce these serious effects upon the eyes, but after a little bathing with cold water, and rest in the recumbent position for a couple of hours, they would have again resumed their natural condition. At the same time that these effects were produced upon the mucous membranes, the skin of the face and neck was also affected, so as to cause a sensation of itching something similar to what exists in a mild attack of nettle-rash. If I continued

ORGANS OF CIRCULATION.—WATER-VASCULAR SYSTEM.
"LATERAL AND MEDIAN LINES."

Von **Siebold** was the first to describe* an excretory system in the Nematoids having a mid-ventral opening in the anterior part of the body. In his 'Manuel' he speaks of this discovery thus:—"Chez plusieurs Nématodes, on observe, à la face ventrale et à une plus ou moins grande distance de l'extrémité cephalique, une petite fente transversale entourée d'un sphincter. Chez quelques espèces, il en part deux canaux intestinaux, et qui, chez d'autres, sont accompagnés de deux autres canaux qui se portent en avant. Les usages de la matière incolore et homogène sécrétée par ces organes ne sont pas encore connus" (p. 140). Since the date of **Siebold's** first observation, no great accession to our knowledge concerning these structures has been hitherto made, and the opening in the

---

to work for about two hours in spite of these symptoms, a general feeling of lassitude and weariness was produced, sometimes amounting to an actual sense of prostration, which would, however, all pass off on desisting from the work and lying down for a few hours. After a few weeks another symptom was superadded, in the form of an asthmatic difficulty of breathing, owing apparently to a constriction of the trachea and of the larger bronchial tubes, which was first noticed about one o'clock one night shortly after going to bed. Without any warning I felt a kind of constriction of the upper air-passages with great difficulty of breathing, each inspiration and expiration being accompanied by an almost musical wheezing sound. This lasted for about three quarters of an hour, when there came a gradual relaxation of the spasm, and all was well again. Such attacks as these gradually became more frequent, generally occurring in the night or evening, lasting longer and often associated with a spasmodic cough, so that much against my inclination I was at last compelled to abstain from any further examination of these noxious individuals. My system at length became so sensitive to the emanations of this animal that I was even unable to wear a coat which I had generally worn during these investigations, without continually sneezing and suffering from other catarrhal symptoms. Avoiding this and other sources of irritation, after a period of about two months every vestige of these symptoms had disappeared, and continued absent till May 1864. During this interval I had never looked at a specimen of *A. megalocephala*, neither did I once experience any of the old asthmatic difficulty of breathing. For one day in the beginning of May I did work with this animal again; not so much sneezing and actual irritation was produced at the time, and I was full of hope, but in the evening came one of the old asthmatic attacks, and the influence produced by this one day's work did not completely exhaust itself till the middle of June—a period of nearly six weeks. During all this intervening time I had been subject to occasional spasms and difficulty of breathing. Subsequent isolated periods of work with this Nematoid have also shown me that it takes from one month to six weeks for its effects entirely to disappear. In the spring of this year I again worked daily with these animals for nearly a month, till the symptoms became so severe as absolutely to compel me to desist. A certain change had come over their influence upon me. I now suffered far less from the more local irritating effects, and much more from the severity of the asthma and spasmodic cough. There was a curious kind of periodicity too about the worst attacks; they generally occurred between five and six o'clock in the morning, and so regularly was this the case that it was almost needless for me to look at my watch, on awaking, to ascertain the hour. These attacks would sometimes last for more than two hours, accompanied by extreme dyspnœa and the most distressing paroxysms of cough. Then at last came a gradual relaxation of the spasm, accompanied by a secretion of thin mucus from the bronchial tubes, followed by an absence of cough and natural breathing for twelve or even twenty-four hours. Not having anatomized these animals since, I have again been entirely free from such symptoms for nearly two months. No effects of this kind were produced by working with *A. lumbricoides*; neither does *A. megalocephala* appear to have affected Dr. **Schneider** or other anatomists in the manner I have just been stating.

* In a Dissert. by **Bagge**, 'De Evolut. Strong. Auric. et Ascar. acuminat.' 1841, p. 13.

ventral region has been rather a stumbling block to anatomists on account of the different bodies with which it was connected; in some cases it appeared as the exit of a system of tubes, whilst in others it was connected with glandular bodies of different sizes, sometimes single and sometimes double; and lastly, WALTER[*] almost certainly alluded to the same opening when he spoke of an anterior ventral sucker existing in the young of many Nematoids, which he believed either to retrograde or entirely disappear in the adult animals. There can be little doubt, however, that we may dismiss this statement of WALTER'S at once as being altogether erroneous. And if it be carefully borne in mind that no observer hitherto has ever discovered more than a single aperture in this situation, I think I shall be able to simplify the whole subject, and also be able to advance cogent reasons for the belief that all the various bodies hitherto met with in connexion with this ventral aperture, are only modifications in the development of one common system answering to the so-called "water-vascular system," so well known to exist in the *Trematoda* and other animals.

The most elementary structures met with in connexion with the ventral opening have been figured and described by Dr. LEIDY[†] in a species of *Hystrignathus*, and by EBERTH[‡] in *Ascaris oxyura* and *Oxyuris ambigua*, in which minute saccules are met with, exhibiting a very rudimentary condition of the so-called "ventral gland." Amongst the free Nematoids, in *Cyatholaimus ornatus* (Plate XXVIII. fig. 36), *Sphærolaimus hirsutus*, the members of the genus *Enoplus* and others, we find it slightly more developed, inasmuch as it exists as a tubular organ extending from the ventral aperture near the middle of the œsophagus, to or nearly as far as the termination of that organ. It has granular contents, and its calibre is uniform except at its blind extremity, where it is very slightly enlarged. In *Linhomœus hirsutum* and *L. elongatum* it is a little longer, extending as far as the commencement of the intestine, which is compressed by the more developed condition of its blind termination. This appears of a dilated pear-shaped form, and is filled with granular contents, in which is imbedded a clear, solid, homogeneous looking body or nucleus[§]. This or the former represents the condition of the ventral gland in most species of the marine Nematoids, and it seems present in almost all the genera. In the land and freshwater species, however, I have recognized a ventral aperture and gland only in the members of four genera, *Aphelenchus*, *Cephalobus*, *Tylenchus* and *Plectus*, and in these it is somewhat modified in form. The duct, instead of being a wide membranous tube, is here a narrow and rather rigid structure, extending with a gentle curve towards the centre of the body, as may be best seen with adult specimens of *Tylenchus tritici* (Plate XXVIII. fig. 17), or having altogether a twisted direction, being two or three times bent upon itself, as occurs in the various species of the genus *Plectus* (Plate XXVIII. fig. 14.). It is extremely difficult to ascertain the precise mode of termination of this duct, but after the most prolonged examinations I am enabled to assert pretty confidently that in *Tylenchus Davainii* this tube communicates with a rather small thin-walled ovoid sac (Plate XXVIII. fig. 20), with no very definite contents*. Probably a somewhat similar structure obtains in all these four genera. EBERTH states that he has seen in some marine Nematoids the ventral gland composed of two similar parts terminating at a common ventral aperture†, which is an arrangement identical with what has now been recognized in many parasitic species. I have seen distinctly in *Strongylus filaria* two elongated glandular bodies terminating by a short common portion, which opens externally by a single median orifice (Plate XXVII. fig. 8). Each of these bodies has the same structure as the single gland met so commonly amongst the free Nematoids, that is to say it is white in colour and dilated at its posterior extremity, enclosing granular contents and a clear, homogeneous, nucleiform body. These glands are, however, longer, and extend further backwards than any we have yet met with. MEHLIS‡ appears to have recognized the dilated portions of these organs in *Strongylus hypostomus* as long back as 1831, whilst EBERTH has lately recognized the entire organs in *Strongylus retortæformis*, *S. commutatus*, and *S. striatus*; two posterior tubes were also spoken of by Von SIEBOLD in connexion with the ventral aperture of *Strongylus auricularis*, so that I think we may fairly look upon this as the typical form of the organ in the genus *Strongylus*. Similar organs are described and figured by KÜCHENMEISTER§ as existing in *Anchylostomum duodenale*, and by EBERTH‖ in *Sclerostomum dentatum*, whilst I have myself recognized the outlet and commencement of the tubes in *Sclerostomum equinum*¶. In *Heterakis acuminata* there is a large transverse opening in the ventral region opposite the termination of the œsophagus which communicates with a dilated termination of the ducts, though I could recognize no distinct ampulla-like body, such as was figured by SCHNEIDER**. This was one of the early species in which two posterior tubes were traced in connexion with the ventral aperture by Von SIEBOLD, which are, I suspect, similar in character to those which we have just been describing. I have also recognized a ventral opening with a large tube proceeding from it in *Heterakis vesicularis*, which I think will very likely prove to be the terminal portion of two similar glandular bodies. This structure does not seem to have been noticed by EBERTH, since he mentions nothing of it in his account of the anatomy of the animal.

---

[*] *Vide* KÜCHENMEISTER (Syd. Soc. Transl.), p. 365 and note.

[†] Smithson. Contrib. 1853.

[‡] Untersuch. über Nemat. Taf. viii. 9, 10.

[§] *Vide* figures, Trans. of Linn. Soc. vol. xxv.

---

[*] This tube gradually becomes lost to view over the intestine, and DAVAINE (Rech. sur l'Anguill. du blé niellé, 1857) imagined it to be an excretory duct in connexion with the cellular lining of the alimentary canal.

[†] I have met with quite an exceptional condition of things in *Leptosomatum elongatum*. In this animal there are two lateral tubes extending along by the side of the œsophagus for about two-thirds of its extent, each of which opens by a lateral aperture on either side of the head, close to the mouth (Trans. of Linn. Soc. vol. xxv. pl. xii. fig. 156). In structure each tube much resembles that of a ventral gland, which, however, is absent in this and two or three other allied species at present located in the same genus. Are they homologous with the salivary tubes described by OWEN in *Gnathostoma*?

[‡] OKEN's Isis, 1831, p. 81. Taf. ii. fig. 6. MEHLIS thought these organs opened into the mouth, and fancied they poured out an irritating fluid destined to increase the secretion of the mucous membrane to which the animal was attached.

[§] Syd. Soc. Translation, 1857, p. 385.

[‖] Untersuch. über Nemat. p. 66. Taf. xviii. 3.

[¶] The *Strongylus armatus* of many authors, and the *Sclerostomum armatum* of RUDOLPHI and DIESING.

[**] MÜLLER's Archiv, 1858. Taf. xv. fig. 7.

I have now to notice considerable modifications of this structure met with amongst other Nematoids. Cloquet[*] was, I believe, the first to speak of an axial vessel contained within the lateral cords of *Ascaris lumbricoides* and *A. megalocephala.* He describes the colour of these lateral bands, in a manner in accordance with my own observations, as very variable in different individuals, adding, "Quelquefois elles sont blanchâtres ou grises, d'autre fois d'un rouge assez vif[†] ou d'un brun obscur; mais une chose digne de remarque, c'est que ces couleurs ne sont pas uniformes dans toute leur longueur; que très-faibles dans un endroit, elles ont beaucoup d'intensité dans un autre." He also spoke of each vessel leaving its band anteriorly, "s'anastomoser avec celui du côté opposé, en formant une arcade simple dont la convexité est antérieure, et de laquelle on ne voit sortir aucun filament." Then followed the observations of Blanchard[‡], who not only recognized but succeeded in injecting these same axial vessels and their anterior communicating branch. He spoke also of an enlargement of the vessel and "une sorte de petite poche" existing on the right side of the arch, which he says "me paraît devoir être considérée comme étant véritablement un vestige de cœur." He maintains also that in each lateral cord there is a second vessel, "très-grêle," lying almost immediately beneath the integument; though he says nothing concerning the anterior distribution of these second vessels or the posterior terminations of either set. He does, however, go so far as to state that this arrangement of the circulatory apparatus is perfectly characteristic of the order *Nematoidea*, since he has been able to recognize it in the most different types. He says, "J'ai examiné les vaisseaux chez les Trichocéphales, les Filaires, les Sclérostomes, les Oxyures, etc.; partout j'ai pu constater une disposition exactement analogue." That this description is incorrect as regards the *Ascarides*, I have not the slightest doubt, and there is even more reason for believing it at variance with what actually exists in the other genera mentioned. The next anatomist who contributed to our knowledge concerning these vessels in *Ascaris megalocephala* and *A. lumbricoides* was Dr. Schneider[§]. He ascertained that the arched communication gave off a short straight prolongation in the middle of its course, which brought these vessels into relation with the exterior by means of an aperture in the mid-ventral region a short distance behind the mouth. The figure he gave on this occasion was rather incorrect, though he has since given a much more truthful representation of this arch of the vascular system in a recent paper in the same periodical[‖]. This representation shows the rudimentary heart of Blanchard to be a large cell filled with granules situated in the thickened parietes of the vessel, at the left side of the arch. Schneider also gives an enlarged representation of one of the lateral bands of *Ascaris megalocephala*, in which he correctly represents the contained vessel situated near the internal surface of the band, and also pourtrays a chink (Spalt) or split extending for some distance into its substance* from and in a direction at right angles to the integument, as well as a marked difference in histological structure between the band itself and the granular layer on which he describes it as resting. As regards these latter characters I am unable to agree with SCHNEIDER. I have succeeded in making remarkably thin transverse sections of these lateral bands, both when they were in a moist condition (with a VALENTIN'S knife) and in the dried animal. These sections have been most successful both with *Ascaris megalocephala* and *A. lumbricoides*, and in neither have I been able to recognize the slightest trace of any vessel in the situation mentioned by BLANCHARD, or any natural solution of continuity corresponding to what SCHNEIDER has described. Artificial cracks or fissures are, however, by no means uncommon (which is scarcely to be wondered at considering the nature of the tissue in question), and an examination of the figure Dr. SCHNEIDER has given, is far from discountenancing this view of the possible explanation of what he has represented. With regard to the histological structure of the lateral band, I believe this to be absolutely identical with that of the deep cellulo-granular layer of the integument, and to be in short nothing but an intermuscular development of it. No line of demarcation exists between them, and they both consist of the same elementary constituents (Plate XXIII. figs. 5 & 16), being made up of a dense aggregation of large, highly refractive particles† or granules, together with nucleated cells and a few interspersed fibres. These lateral bands are considerably larger in *A. lumbricoides* than in *A. megalocephala*‡, especially in the anterior parts of the body, and their structure is also denser, owing to a firm fibrous network existing within them, which is most developed next the external integument and extends thence inwards to the longitudinal vessel. This fibrous framework seems to be present principally in the anterior portions of the bands, and does not appear to exist at all in those of *A. megalocephala*. In this latter animal also the contained vessel is not only relatively but absolutely larger than in the last-named species, and may be isolated with ease. Although the arrangement of the vessels or canals in these two species is identical, this can be much better made out in *A. megalocephala*

---

[*] Sur les Vers Intestinaux, 1824, p. 38.

[†] This appearance seems due to the colour of the fluid in the axial vessel.

[‡] Ann. des Sc. Nat. 3^{me} sér. t. vii. (1847) p. 126.

[§] Müller's Archiv, 1858, p. 426. Taf. xv. 3 *a*.

[‖] Idem. 1863. Taf. i.

* EBERTH, I fancy, has followed SCHNEIDER in this particular, and has given a most exaggerated representation of this chink (Spalt), which figure has been introduced by Dr. COBBOLD into his recent work on "Entozoa," at p. 305. I believe EBERTH merely to have followed SCHNEIDER as regards this structure, because he does not appear to have examined this *Ascaris* very fully, and I can find no mention of the structure, except in his explanation of the figure.

† These biscuit-shaped particles have often been spoken of as fat particles, but they are not soluble in a mixture of boiling alcohol and ether, and I suspect their composition would ally them more closely to the protein group of elements (MÜLLER'S Archiv, 1858. Taf. xv. 2).

‡ When the inner surface of the bands of *A. megalocephala* is examined with a lens, it often presents a sort of honeycombed or reticulated aspect for a short distance. In *A. lumbricoides*, especially in the posterior halves of the lateral bands, brownish-coloured patches are frequently seen at intervals, seemingly due to a deposit of pigment in its substance. And in old specimens, when different portions of these cords from the posterior part of the body are submitted to microscopical examination, deposits and deviations from the usual structure are by no means uncommon. SCHNEIDER has represented remarkably large cellular bodies as existing in the substance of the lateral bands of *Ascaris acus*.

than in the other. In *A. lumbricoides* a distinct walled vessel does exist, though its isolation from the surrounding tissue is by no means easy; the arch also is less pronounced. Neither in this species nor in *A. megalocephala* could I see, when viewed from within, the straight exit-tube of the arch; it does not seem to lie along in the median line, but to proceed almost directly *outwards* through the muscular layer and integument to the median aperture, which is I think only very slightly anterior in position to the arch itself. It is not easy to follow these vessels in the lateral bands towards the posterior extremity of the body, but after the most careful examination of individuals of these species and of *A. marginata*, I feel quite confident that no posterior union between the vessels exists, but that in all they appear gradually to diminish in size and in the thickness of their walls, and either disappear or dwindle into mere lacunar channels at about the level of the anus. Thus in a specimen of *A. marginata* one of the thick-walled vessels, just behind the arch, measured $\frac{1}{450}''$ in diameter, having a central lumen $\frac{1}{2000}''$ in diameter, whilst close to the termination of the vessel, where I was fortunate enough to be able to isolate it from the band in which it was imbedded, at a distance of $\frac{3}{4}''$ from the posterior extremity of the animal, the diameter of the entire vessel was only $\frac{1}{5000}''$. I have never been able to detect branches of any kind given off from these lateral canals or vessels. Their walls are composed of a dense tissue; and though I have not been able to make out its exact structure, I have no doubt that it is a kind of muscular tissue, capable of contracting and dilating. Contiguous portions of the canals may frequently be seen with a varying calibre; and on the left side of the arch I have occasionally seen the canal very narrow opposite the peculiar, large, more or less round or ovoid cell, enclosed in its thickened outer wall in this situation (Plate XXV. fig. 9). This body is altogether remarkable; imbedded in the very substance of the wall of the canal it has a distinct bounding membrane and is densely filled with small granules, which generally effectually conceal a clear nuclear body existing in the centre. Curiously enough, too, I have detected three bodies presenting a precisely similar appearance in what I believe to be muscular tissue, surrounding the rectal termination of the intestine in *A. megalocephala* (Plate XXV. fig. 5). What their nature can be I have not the slightest idea, neither have I met anything similar to them elsewhere among the Nematoids. In those *Ascarides* having the above-mentioned arrangement of their excretory tubes, a body of this kind seems always to exist on the left side of the arch, and at the same time the walls of the vessel on this side are generally much thicker than on the other. What relationship there is, however, between these two facts I am unable to say, and it seems very difficult to explain why one side of the arch should be larger than the other. The most extreme divergence between the two sides exists in *A. marginata*, in which animal these canals are remarkable, not only for the thickness of their walls, but also for their great proportionate size as compared with that of their containing bands (Plate XXVI. fig. 2). In *A. mystax*, on the contrary (Plate XXVI. fig. 4), the vessels have about the same proportionate development as in *A. lumbricoides*.

An arrangement of the excretory tubes similar to that just described also exists, in all probability, in the genus *Spiroptera*, although the vessels are most likely minute and difficult of detection. I found this belief upon the following evidence. EBERTH has carefully examined three species of the genus, and makes no mention of the existence of ventral glands in either, though he has described and figured* a delicate axial vessel in the lateral band of *Spiroptera uncinata*. He discovered the lateral cervical pores in these animals, and as he looks upon them in the Nematoids generally as lateral openings of the vessels, taking the place of the single ventral pore, he probably never carefully searched for this. SCHNEIDER†, however, does state that the ventral opening exists in *Spiroptera obtusa*, and I have been led to a similar belief from what I have observed in the same animal. The specimens I examined had been preserved for a long time in spirit, and were in a rather poor condition, so that I was quite unable to detect any vessels in the lateral bands. Although I believe they exist, in all probability they are of small size‡. At all events I could not positively make them out, though I did detect a union of the lateral bands beneath the œsophagus (Plate XXVI. fig. 20) close behind the head. Thus a ventral opening was seen by SCHNEIDER, an internal arch by myself, and a contained axial vessel in another species of the same genus by EBERTH. *Spiroptera obtusa* is most remarkable for the great inequality in the size of its lateral bands; in the cervical region of the body they are almost equal on the two sides, but throughout the greater part of the extent of the animal the right is enormously developed (Plate XXVI. fig. 19), forming a great projection, which near its middle occupies nearly one-third of the general cavity of the body. A considerable quantity of fibrous tissue seems to enter into its composition, and both it and the small one of the opposite side seem bisected by an imperfect horizontal septum of this kind.

I have carefully examined many specimens of *Prosthecosacter inflexus*, and in none could I discover any trace of a ventral gland. At the anterior extremity, however, close behind the mouth, I detected a distinct funnel-shaped depression, this being the outer termination of a channel through the integument in the ventral region, at a level very slightly posterior to that of the capillary lateral pores (Plate XXVII. fig. 3). From the lateral bands, also, delicate processes were given off on each side, which met at the ventral aperture, but neither in these, nor in the lateral bands § themselves have I detected any actual vessel. If it exists, as the structures would seem to point out, it is probably very small.

I have now to describe some remarkable modifications in the arrangement of these vascular or excretory canals which are met with in the so-called *Filaria piscium*, and in two animals at present included in the genus *Ascaris*, viz. *A. osculata* and *A. spiculigera*. In

---

* Untersuch. über Nemat. Taf. ix. 6.

† MÜLLER's Archiv, 1858.

‡ I have since ascertained that SCHNEIDER does report the existence of such delicate vessels communicating with one another anteriorly (*Vide* EBERTH, Untersuch. über Nemat. p. 64).

§ It is very difficult to detect a delicate vessel in these bodies, either in their longitudinal direction, when the lateral bands are solid and opaque as in this animal, or even more so in transverse sections; a delicate-walled vessel becomes obliterated by the mere mechanical process of making the section.

Filaria piscium SIEBOLD[*] described "un organe rubaniforme caché dans la cavité du corps, parcouru par des canaux formant un réseau, et qui rappelle les lemnisques des Acanthocéphales." He also stated that he had met with a similar organ in *A. osculata*. SCHNEIDER confirms[†] SIEBOLD'S account of the existence of this organ in a species of *Filaria piscium*, and discovered that the main canal traversing it leaves this body to open externally. He is uncertain whether to look upon it as a special organ, or as a part of the ordinary water-vascular system, and states moreover that the lateral band of the left side appeared to be wanting in the animals he had examined. It must be borne in mind that under this same name of *Filaria piscium* several different species are probably included. I do not know from what animal the immature Nematoids examined by SIEBOLD and SCHNEIDER were taken. In all likelihood they were not from the Haddock, since in animals removed from beneath the peritoneal membrane of this fish I have found a different structure prevailing. In them, both lateral bands were present and of the same size (Plate XXII. figs. 6 & 8), though only the one of the left side possessed an axial canal. This canal could be seen most distinctly when the entire animal was examined. It was provided with distinct walls having an appearance of internal septa at intervals (Plate XXII. fig. 7), pursued an undulating course, terminating apparently near the extremity of the body in a cæcal ending, and left the lateral band anteriorly to open in the mid-ventral region opposite the termination of the anterior third of the œsophagus. Nothing corresponding to a lemniscus could be detected, and no vessel seemed to be given off from this main canal in any part of its extent. This arrangement is very interesting, inasmuch as it may be considered directly intermediate between what has been already described as existing in *A. lumbricoides*, &c., and what I have met with in *A. osculata* and *A. spiculigera*[‡]. In both these latter animals I have found a canal on the left side of the body only, which leaves the substance of the lateral band, far forwards, to gain the ventral region, where it appears to open at the anterior extremity of the body between the two lower head lobes. In both it gives off numerous branches in the substance of the left lateral band, and ramifies still more minutely in a peculiar, elongated development from this structure existing in the anterior part of the body (Plate XXVI. figs. 6 & 7). This prolongation constitutes the so-called "lemniscus" of SIEBOLD. The ramifications of the canal are confined to this lemniscus, and to the portion of the lateral band anterior to it; so that no vessels or canals can be found on either side in the lateral bands of the posterior half of the body. In both animals the lemnisci present a somewhat similar appearance; they are elongated structures lying by the side of the left lateral band, deeper in tint than it and of a light brownish hue, varying in different individuals in width and thickness, and also in length from ½″ to 1″. The lateral bands themselves in both these species have a kind of bilobed structure, and the lemniscus seems to be a growth from the anterior part of the ventral division of the band on the left side, which extends backwards in contact with it, and gradually terminates by a narrow posterior extremity. In transverse sections, though they are in close apposition, the demarcation can always be detected between this body and the left lateral band, as well as the existence of a tissue connecting it with the band of the opposite side. This tissue is composed of an intermixed mass of fibres and nucleated cells, similar to those existing in the deep integumental layer. This difference exists between the lemnisci in the two species: in *A. osculata* it seems to be hollowed out in the greater part of its extent into a flat elongated oval cavity, and the main canal runs along the free border of the organ (Plate XXVI. fig. 6) distributing branches on all sides; whilst in *A. spiculigera* only the rudiment of a central cavity exists near the middle of the organ in the form of a small somewhat fiddle-shaped cavity (Plate XXVI. figs. 14 & 16), and with the exception of a slight detour around this, the main channel runs along its centre, distributing branches freely as before. These branches* form at their extremities the finest possible network of interlacing canals (Plate XXVI. fig. 7). Whether or not they ever end in free extremities I was unable to determine; they all seemed to possess distinct though delicate walls, and no cilia could be detected within them. Their walls are probably contractile, and in the main canal I detected the remains of some granular contents. Posteriorly the central canal may be seen gradually to diminish in size, and terminate almost imperceptibly at the narrow extremity of the lemniscus itself (Plate XXVI. fig. 6).

---

[*] WIEGMANN, Archiv, 1838, i. p. 310. *Idem* in Man. d'Anat. Comp. 1850, vol. i. p. 135.

[†] MÜLLER'S Archiv, 1858.

[‡] I was induced to examine this latter animal on account of a peculiar structure stated to exist in it by DUJARDIN, which he described in these words: "*Cloison* séparant l'intestin de l'uterus, et formée par un cordon jaune glanduleux épais, que des membranes blanches unissent aux deux cordons latéraux" (Hist. Nat. des Helminth. p. 206). The only body at all answering to this description is what I am now about to describe.

I now come to the last principal modification of these canals as existing in the Nematoids. When SIEBOLD first called attention to these tubes, he stated that in *Ascaris dactyluris* and in *A. paucipara* two anterior branches, as well as two posterior, existed in connexion with the ventral aperture. SCHNEIDER† also represented a similar arrangement in *Pelodytes strongyloides*, *Dacnitis esuriens*, and *Leptodera flexilis*, whilst at an anterior period Professor HUXLEY‡ had more fully described a similar distribution of contractile canals in a Nematoid from the Plaice, which he spoke of as an *Oxyuris*. I have searched in the same fish and discovered in it an animal in all respects similar to that represented by HUXLEY. This animal, however, I feel almost certain is not an *Oxyuris*, but the *Dacnitis esuriens*§ of DUJARDIN and SCHNEIDER. In all other respects I am able to confirm the statements concerning it made by HUXLEY. The ventral aperture is situated far back near the posterior extremity of the œsophagus; it seems to lead into a rather indistinct sacculated organ, which in its turn communicates (Plate XXVII. fig. 11), in a manner that I was unable precisely to make out, with the longitudinal canals close to the junction of the anterior and posterior branches. These canals are distinct walled tubes, which perforate and are situated in the lateral bands of the animal

---

* Best revealed by immersing the organ in strong acetic acid.

† MÜLLER's Archiv, 1858 and 1860.

‡ Med. Times, 1856, vol. ii. p. 384.

§ *Cucullanus heterochrous* of DIESING, Syst. Helminth. vol. ii. p. 241.

(Plate XXVII. fig. 13, *b*, *b*). Just posterior to the position of the contractile sac, by means of which they communicate with the exterior, they bend towards the ventral aspect of the body, and the acute angle which the anterior and posterior branches of the same side make with one another is merely due to a bend of the canal, as I have frequently seen their contents pass in an oscillating manner down one limb, through the bend, and up the other, in both directions. As described by HUXLEY, the posterior canals terminate cæcally close to the posterior extremity of the body (Plate XXVII. fig. 11), and I have in addition seen the anterior branches terminate in a similar manner opposite the middle of the pharyngeal cavity. No branches seem to be given off from these canals in any part of their extent; they are of a somewhat varying calibre, the anterior branches being rather broader than the posterior, and in both may be recognized a series of imperfect septa extending inwards from the walls of the canals. Their contents are a clear transparent fluid, in which a number of minute molecules are suspended; these seem to be driven backwards and forwards, partly by the movements of the animal, and partly by the contraction of the canal containing them. No cilia can be detected in their interior. This is the only Nematoid in which I have actually seen contractions of the lateral canals. The lateral bands containing them are of much the same structure as others I have already described, only they often contain a series of nuclei, and what appear to be clear spaces*.

We have thus seen that the structure of the lateral bands is by no means always the same, and that longitudinal vessels do not exist within them in all cases; and, I must say, I think it highly desirable that the descriptions of these structures as they are met with in some species of the genera *Heterakis*, *Oxyuris*, and *Strongylus*, given by EBERTH† and WALTER‡, should be confirmed. In *Heterakis vesicularis*, EBERTH described the lateral band as containing a delicate central vessel; but if such a vessel really exists it must form part of an arrangement different from any that has yet been described. I have somewhat hastily examined individuals of the same species, and was quite unable to detect such longitudinal vessels by any external inspection. And on account of the small size of the animal I was unable to succeed, as EBERTH appears to have done, in making satisfactory transverse sections. EBERTH does not seem to have recognized the ventral opening and tube, which from its general appearance, and from the fact of similar structures existing in an allied§ animal (*Heterakis acuminata*), I believe to be the terminations of a single or double ventral gland. Certainly it is not likely to be an outgoing tube from a vascular arch formed from lateral vessels as in *A. megalocephala*, since the tube is here more than twice as broad as the whole lateral band (Plate XXII. fig. 10, *a*, *b*). I am sorry I had neither time nor specimens sufficient to examine this animal more fully. WALTER has described the lateral bands of *Oxyuris vermicularis* as closely resembling those of *Ascaris lumbricoides*, and like them containing an axial vessel; but then WALTER differs in so very many points from other observers, not only as regards the actual presence or absence of certain structures, but also as regards the interpretation of others well known and recognized to exist, that it would be desirable to have this observation verified by some other investigator. SCHNEIDER has been quite unable to discover the usual anterior ventral pore in this animal, neither have I, after the most careful search, been able to find it; and, notwithstanding the transparency of the animal, I certainly never could discover any trace of an axial vessel contained in the lateral bands. In *Oxyuris spirotheca*, moreover, SCHNEIDER has equally failed to discover a vessel within the lateral band; according to him it is made up solely of the usual admixture of granules and cells. The lateral bands of three species of the genus *Strongylus* have been described by EBERTH. In *S. tenuis* and *S. commutatus* he says may be seen the simplest condition of the lateral lines; in the former they consist each of a simple row of small cells, such as may be seen in many of the *Trichosomata*; in *S. commutatus* also the lateral lines are narrow and made up of small cells, whilst in this animal EBERTH also reports the presence of a double ventral gland. He states, however, that a different structure is met with in *S. striatus*, the lateral band being well developed, containing granular matter and nuclei, and also a delicate axial vessel; but in this species he does not seem to have certainly detected a ventral gland; he speaks of two organs, indeed, within the cavity of the body, though he also states that these seemed to be prolongations from the œsophagus, and that he was unable to recognize any external orifice. The organization of this animal must therefore be considered as still doubtful.

---

* The representation SCHNEIDER has given of the lateral bands in *Dacnitis esuriens* is I believe erroneous. It seems to me that he has been misled by the appearance of the indistinct intestinal cells lining the very broad portion of the alimentary canal in this situation. Their very light colour and almost entire freedom from granular contents, was quite suggestive of cellular bodies, such as SCHNEIDER has figured in the lateral bands themselves (*loc. cit.* Taf. xv. fig. 8).

† Untersuch. über Nemat. 1863, p. 63. Idem in Würzb. Naturwiss. Zeit. 1860, Erst. Bd. p. 41.

‡ VIRCHOW's Archiv, 1860.

§ I am quite aware that the difference between these two species would warrant their being placed in different genera, but still their resemblances are such that the genera would be allied.

EBERTH seems to have examined the *Trichocephali* and *Trichosomata* much more fully than any other observer, and he makes no mention of the existence in them either of any modification of the ventral gland, or of vessels contained within the lateral bands. The structure of the longitudinal bands, both lateral and median, is of two principal kinds in these animals; and although they present the greatest variety as regards arrangement and relative size in different species, their actual histological structure is almost uniform throughout the whole group. He describes the simplest form as consisting of a long string of small cells or nuclei, which may either form a single row occupying the whole breadth of the band, or when the band is larger lie in contiguous rows, the several cells of which are separated from one another by a finely granular material*. The size of the single cells is variable; and whilst the smaller ones contain only a minute punctiform nucleus, the larger are beautiful polygonal bodies, with a well-marked nucleus and granular contents. The other modifications of the longitudinal bands met with in these animals are those concerning which I had to speak in the section on the tegumentary organs, as being connected with such an enormous number of integumental pores. On this point, however, my views are, as before stated, at variance with those held by Eberth. As pointed out by this observer, the bands in connexion with these integumental pores frequently disappear in the posterior parts of the body, whilst the others usually extend along the entire length of the animal. In the *Trichocephali* but one such band seems to exist in the dorsal part of the anterior thread-like portion of the body, whilst in the genus *Trichosoma* the greatest variety prevails*. Thus in *T. resectum* and *T. plica* two equal bands of this kind exist in the lateral region of the body; in *T. spirale* there is a broad dorsal and a narrow ventral band, and in *T. aërophyllum* just the opposite arrangement; whilst in *T. dispar* two broad lateral bands as well as a narrow dorsal one are met with. In many of the *Trichosomata* (in accordance with what I have myself seen in *T. longicolle*) Eberth represents what I believe to be the integumental pores, situated over bands composed of ordinary cells. He, however, describes the structure existing in the dorsal region of the *Trichocephali* as being composed of an aggregation of columnar, polygonal cells†, and this accords pretty closely with what little I have been able to ascertain concerning its structure. I distinctly recognized that it presented a kind of loculated appearance in some thin transverse sections which I succeeded in making of the anterior extremity of *T. affinis*, though I was unable to make out its exact structure and relation to the integumental channels immediately external to it. I think it quite possible that this band, as well as the other forms of the longitudinal lines met with in the Nematoids, may be a development—only a more specialized one—of the deep cellular layer of the integument. With regard to the existence of secondary median lines in these animals, and many interesting details concerning the remarkable variations in the proportionate size of the longitudinal bands generally, Eberth's valuable Monograph should be consulted.

---

* In connexion with this structure of the lateral band it will be well to notice also what EBERTH says of the so-called granular layers in these animals. His words are, "Dicht unter der Haut trifft man eine zarte feinkörnige Schicht, die mir aus sehr zarten Zellen zu bestehen scheint."—Unters. über Nemat. p. 46.

It has been already stated that in *Strongylus tenuis* and *S. commutatus* a simple cellular condition of the lateral lines may be seen, such as is so common in the group concerning which we have just been speaking, and, according to the observations of both Eberth and myself, this is the condition of things most commonly met with amongst the free Nematoids. In many forms which Eberth has well represented, the simple cellular structure is most distinct. It may be seen amongst the species of the genera *Enoplus*, *Oncholaimus*, *Leptosomatum*, *Dorylaimus* and many others, whilst in some the individual cells cannot be made out, and a simply granular band appears to exist (Plate XXVIII. figs. 34 & 35). In many genera, moreover, amongst which I may mention *Rhabditis*, *Tylenchus*, and *Plectus*, I have failed to recognize any trace of a lateral band.

---

* *Vide* Eberth's Unters. über Nemat. Taf. vii.

† He represents the muscular layer as covering the whole inner surface of this body in *Trichocephalus dispar*: concerning this animal I can say nothing, though I am quite positive that such is not the case in *T. affinis*—here the cellular band is still an intermuscular organ.

Nothing that can be called a lateral band is met with in *Dracunculus medinensis.* In this animal, it is true, an unusually wide intermuscular space exists (Plate XXV. fig. 14), covered by a thin stratum of the deep cellular integumental layer; and though no prominence whatever can be observed, we must undoubtedly look upon this portion of the granulo-cellular layer lining the chitinous external integument, as the undeveloped homologue of what, in most Nematoids, constitutes the lateral band. We see in this stratum, thin as it is, the characteristic nucleated cells[*], and running along its median line a most delicate vessel only $\frac{1}{8000}''$ in diameter. What is the nature of the peculiar ganglionated cord (in the same position and in contact with the longitudinal vessel) which I formerly described as a nerve, I am now quite unable to understand[†]. I have been able to ascertain nothing concerning it by means of transverse sections, except that it seems to constitute a flat band whose situation is not even marked by a thickening of the cellular layer in the middle of the intermuscular space. The anterior and posterior terminations of these bodies, as well as of the longitudinal vessels, is still unknown, and must be made the subject of future investigation.

The *median lines* have been frequently mentioned incidentally, so that I have now little to add concerning them. As before stated, they do not always exist, but when present I believe their method of formation and structure to be similar to that of the lateral lines. I therefore look upon them also as developments of the deep layer of the integument. They are usually small and narrow, in accordance with the nature of the intermuscular interval in the mid-dorsal and mid-ventral regions; but, as we have already seen in certain species of the genus *Trichosoma*, the dorsal or ventral bands may much exceed the lateral in width, and a study of these animals alone is sufficient to support the opinion of the absolute identity, as regards histological structure, of the lateral and median bands in the Nematoids—an opinion, however, which I had held long before I was aware of the additional proof afforded by the interchangeable nature of these structures amongst the *Trichosomata.* Accessory median lines, one on each side of the primary, exist in many of these animals, and the same arrangement appears to prevail in *Prosthecosacter inflexus* (Plate XXVII. fig. 4, *b′*, *b′*). In this animal they form the narrowest possible prolongations up between the muscular bundles, and are principally recognizable when the body of the animal is slit open and the internal organs removed, by the slight swellings which appear in their course, at intervals, along the surface of the longitudinal muscles. The ordinary single median line in the dorsal and ventral region may be best studied in *Ascaris lumbricoides* and *A. megalocephala*, and in *Spiroptera obtusa.* They seem to me absent altogether in *A. osculata*, *Cucullanus heterochrous*, and a species of *Filaria* which I have examined, whilst EBERTH has also failed to recognize them in *Strongylus tenuis* and *Sclerostomum dentatum.* They very likely exist in some species of free Nematoids, although their minute size has hitherto prevented their detection.

---

[*] *Vide* Trans. of Linn. Soc. vol. xxiv. pl. 21. fig. 25.

[†] When I formerly made this statement I did not know so much concerning Nematoid Anatomy, and although I never felt quite satisfied about its histological resemblance to a real ganglionated nervous cord, I at the time described it as such simply by way of exclusion—there seemed to be nothing else which it could possibly be.

Eberth still believes that the median lines in some Nematoids constitute a part of the water-vascular system, whilst **Walter** goes much further, and states that they anastomose with the lateral vessels, and also send off a number of transverse branches on either side. These transverse branches are what **Walter** formerly described as peripheral nerves, but which have now been most conclusively shown by **Schneider** and myself to be merely transverse prolongations from the muscle-cells to the median lines. **Schneider** does not look upon the median lines as belonging in any way to the vascular system. I have no doubt concerning the general structure of the median lines; and the description given of them in several species, both by **Walter** and **Eberth**, to the effect that they are composed of a delicate membrane enclosing a number of highly refracting particles, is not only in accordance with my own observations, but also in harmony with the belief that they are developments of the deep integumental layer. As I stated, however, in my paper upon the Guineaworm, these structures in this animal have a somewhat different formation, not presenting the granules and being of a more fibrous nature; and after the most careful investigation of them, I came to the conclusion that they were hollow, and in fact constituted vessels of some kind. At the same time I stated that I had frequently been almost led to believe that a lacunar channel did exist in the median lines of *Ascaris lumbricoides*. The difficulties besetting the investigation of these structures is extreme, and I am still somewhat undetermined upon this point. I have fancied from time to time that a lacunar channel existed in these bodies both in *A. lumbricoides* and *A. megalocephala*, but can say nothing positive upon the subject. The existence of peculiar transverse vessels to be presently described in the deep integumental layer of both these animals, also seems to lend support to this idea. Dr. **Schneider's** views concerning the structure of the median lines in the *Ascarides* have already been alluded to when speaking of the nervous system.

A statement has now been made of almost all that is at present known, not only concerning the nature of the structures in connexion with the anterior ventral aperture of the Nematoids, but also concerning the formation of the lateral and median bands. And at present the balance of evidence is decidedly in favour of the view I have adopted, that the so-called ventral glands met with in some Nematoids, and the axial tubes seen in the *Ascarides*, *Cucullanus*, and other animals—organs communicating with the exterior by a median pore—are all only modifications of one and the same structure. From the abortive saccule of *Oxyuris ambigua*, we see the organ progressively developing into a simple tube in some of the free Nematoids, a tube with a dilated nucleated extremity in others, and in the *Strongyli*, *Sclerostomata*, and others, we get a bifurcation of the organ, which still opens, however, by the same median pore. In *Ascaris megalocephala*, *A. lumbricoides*, &c., the outgoing tube and the arch are still situated, like the ventral glands, in the general cavity of the body, so that up to a certain stage of development we may imagine the structure of one of these animals, so far as this organ is concerned.

closely to resemble that of a *Strongylus*; but at a more advanced stage a specialization occurs, the extremities of the gland no longer proceed with their development in the general cavity of the body, but each tending towards that of its own side, perforates the lateral band and continues to extend lengthways in its substance in the form of a uniform tube or vessel. In the *Ascarides* the ventral aperture is situated far forwards towards the head, whilst in other Nematoids, such as *Cucullanus heterochrous**, it is found situated much more posteriorly, opposite the termination of the œsophagus; and here, accordingly, in addition to the two posterior branches which perforate the lateral bands as in *A. lumbricoides*, a still further specialization exists, and two anterior branches are given off to occupy those portions of the bands in front of the median aperture.

In that form of the so-called *Filaria piscium* which I examined, may be seen the rudimentary condition of a more complex arrangement existing in *Ascaris osculata* and *A. spiculigera*. Here a single tube in communication with the ventral pore leaves the cavity of the body to perforate the left lateral band, in the axis of which it exists as a simple unbranched vessel, whilst in *A. osculata* and *A. spiculigera* a corresponding tube, also on the left side, sends off an infinity of inosculating branches which ramify in the substance of the lateral band, and of a special development from it. The tubes in some of these animals have positively been ascertained to be contractile in their nature, and they seem generally to contain a clear colourless fluid with a variable number of small molecules suspended in it. In *A. lumbricoides* the contained fluid is frequently of a reddish colour. Although the body of the ventral glands is generally quite filled with granular matter, still in the terminal portions of their duct I have frequently seen amongst the free Nematoids a clear fluid with suspended molecules. I have especially noticed this in *Symplocostoma longicolle*.

I am fully impressed with the homological identity of these modifications of an excretory organ, as met with in the Nematoids, with that system of vessels in the *Trematoda* and other animals, which, from its invariable communication with the exterior, has been termed a "water-vascular" apparatus. As I shall have again to allude to this subject when treating of the affinities of the Nematoids, I will now merely call attention to the following facts:—that in both Nematoids and Trematodes the nature of the contents in this system of canals is the same, whilst in *Distomum tereticolle*†, as in *A. lumbricoides*, the fluid has been seen of an exceptionally reddish colour; that in some species of Trematodes, such as *Monostomum faba*, *Distomum cirrigerum*, and *Gasterostomum fimbriatum*, there exists in connexion with the external aperture only a simple sac; in others, such as *Distomum chilostomum*, *D. clavigerum*, *D. conjunctum*, *D. luna*, &c., as well as in several species of the genus *Monostomum*, it is a bifurcated organ; whilst in *Amphistomum conicum* ‡ four main branches exist, although each of these sends off an infinity of offshoots.

I have still to speak of two varieties of vessels met with in the Nematoids, which apparently have an independent origin, and no connexion with the system of tubes communicating with the ventral pore. The first variety is met with amongst the various species of four land and freshwater genera, all of which possess certain common characters, and amongst others an extraordinary tenacity of life and power of resuming their vital manifestations after the most prolonged periods of desiccation. These four genera are *Tylenchus*, *Plectus*, *Aphelenchus*, and *Cephalobus*. I have examined the vessels themselves most fully in adult specimens of *Tylenchus tritici**. In this species they are single, unbranched vessels, about $\frac{1}{3330}''$ in diameter, with thin transparent parietes and colourless contents, each pursuing an undulating and in some places an almost convoluted course along either side of the body. They are, certainly, throughout the greater part of their extent, unattached to the parietes of the body, but how they end either anteriorly or posteriorly I have been quite unable to ascertain. I have succeeded in tracing them to within a very short distance of each extremity of the animal, but never could detect either any external aperture with which they communicated, or union of the vessels of opposite sides. From the freedom, however, with which I have seen these vessels extruded with other contents of the general cavity, through ruptures of the posterior part of the animal by pressure of the covering glass, I am inclined to think that, posteriorly at least, they are unattached to the parietes of the body. When whole coils of these vessels were thus brought fairly into view, I never saw the slightest evidence of contraction in any part of their extent, neither could I detect any cilia in their interior; they seemed to contain a clear fluid devoid even of suspended molecules. In the other genera named I have never seen any approach to a convoluted arrangement of these lateral vessels, and they seem to pursue nearly a straight course. In the genus *Plectus*, however, each seems to start from, and to be connected anteriorly by a short narrower portion, with a circular marking (perhaps having a minute orifice in its centre) of the integument (Plate XXVIII. fig. 14). This is all I have been able to ascertain concerning these structures, and it is from what I have seen in *Tylenchus tritici* only, that I have been led to infer as a probability that the similar vessels met with in the other genera, occupy the same position in the general cavity of the body as I have proved them to do in this species. These four genera are further allied to one another by the fact that they alone of the land and freshwater Nematoids yet discovered possess any modification of the ventral gland before described, and that it exhibits essentially the same formation in all the species of these four genera, whilst this formation differs somewhat from the common type.

---

* *Dacnitis esuriens* of DUJARDIN.

† SIEBOLD's Man. d'Anat. Comp. p. 137, note.

‡ COBBOLD's 'Entozoa,' plate 3.

The other vessels in the Nematoids were, I believe, structures first noticed by SCHNEIDER† in *Ascaris lumbricoides*, though neither at that time nor at the present‡ does he take this view of their nature. He is somewhat perplexed by them, but upon the whole regards them rather as nerves than vessels. LEYDIG has also examined these structures, and believes them to be vessels—an opinion which I had, moreover, formed of them at a time when I was quite in ignorance of LEYDIG'S views upon the subject.

---

* Olim, *Vibrio tritici*.

† MÜLLER'S Archiv, 1860, S. 240. Taf. vi. 10 u. 11.

‡ *Ibid.* 1863.

These vessels (assuming them to be such) exist in the substance of the deep cellular layer of the integument mostly in pairs, and extend from median line to median line. They cannot be examined without careful preparation of the animal, of such a kind* as to permit of the longitudinal muscles being entirely stripped from the surface of the granulo-cellular layer after its body has been slit open in a longitudinal direction. The best species for their examination is *A. megalocephala*, owing to the greater size of the vessels and to the readiness with which, in their passage from median line to median line, they may be traced through the substance of the lateral band. I have mapped out inch by inch, as correctly as possible, the entire series of these vessels as I found them existing in a specimen of *A. megalocephala* (Plate XXV. fig. 10), and having examined two other individuals in the same way, I found that they were distributed in the same unsymmetrical manner—more than twice as many vessels existing on the right side of the body as are to be met with on the left. And although I have not mapped out the entire series in *A. lumbricoides*, I have ascertained that in this animal a similar disproportion exists in the number of vessels found on the two sides of the body. I do not think the number or relative positions of the several vessels is absolutely similar in any two individuals of either of these species: small differences exist in different individuals, through a general similarity of arangement prevails. The general course of the vessels may be best seen with a low power of the microscope, when they have the appearance of bright undulating channels distinguishable by the total absence of granules in their course through the dark granular membrane. Magnified to this extent they seem mere lacunar passages only. They may generally be seen running in pairs; starting, for instance, from the dorsal median line at a short distance from one another, we may see them pursuing an undulating course, either parallel with one another or not, till we come to the lateral band, through which they may be seen to pass, generally external to the longitudinal vessel, and apparently unconnected with it in any way, and then through the remaining tract of granular material till they reach the ventral median line, where they may be either closer to one another or further apart than they were at the dorsal line. As may be seen by the figure, during this course the two vessels may cross one another either once, twice, or not at all; they may keep at a pretty uniform distance from one another, or may diverge widely. Where the vessels cross only once, this most frequently occurs during their passage through the lateral band, and in some cases they run so obliquely through this as to appear on the other side at quite a different level from that at which they entered (Plate XXIII. fig. 7, and Plate XXV. fig. 11). More rarely a single vessel may be seen pursuing this same course between ventral and dorsal lines, and, rarer still, a single vessel stretches from one of the median lines to the lateral band only, and there ends. These vessels have an almost uniform calibre throughout their extent, at all events no dilatations may be seen in their course or at their terminations; their breadth varies, however, from $\frac{1}{1000}''$ to $\frac{1}{500}''$ in *A. megalocephala.* When examined with a power of about 200 diameters, it can be seen that the granules between which the vessel lies are displaced by an intervening body, and that there is something more than a mere lacunar canal. It may frequently be seen that one of the vessels composing the pair, in the neighbourhood sometimes of the dorsal, and sometimes of the ventral median line, is more irregular and undulating in its course than usual, and from this portion short branches appear occasionally to arise which extend into the neighbouring granular material. This was also observed and figured by SCHNEIDER. Sometimes, moreover, a slender transverse branch may be seen uniting the two vessels in the same situation; but with these exceptions the vessels appear to be quite unbranched. All attempts to follow them into the substance of the median lines have utterly failed, and after the most careful examination I have also equally failed to discover any channels through the integument opposite their terminations; and I have so repeatedly searched for these in vain, that I can almost confidently assert they do not exist. When portions of the vessels are isolated from the layer in which they are imbedded they appear as flat bands, whitish in colour, and as if composed of longitudinal fibres with minute interspersed molecules, though it is extremely difficult to convince oneself in this way that they are in reality hollow tubes. They have much the appearance of flat solid bands, such as SCHNEIDER believes them to be. But I am almost convinced this cannot be the case, since several times, on examining a portion of the animal in which I had been endeavouring to isolate these bodies, I have found the vessels torn across in some part of their course, whilst the remaining portion still lying in an undisturbed part of the cellulo-granular layer, now no longer occupied the whole breadth of the lacunar channel in this structure—as they all invariably do before they have been disturbed—but was so diminished in size as to occupy no more than one-third of this space. Is it likely that the traction exercised in the act of tearing this structure across would, if it were a solid band, cause it to shrink to this extent? I think not; though this might very easily occur with a thin-walled vessel, such as I believe this structure to be. If they really are solid fibrous bands, what can they be except either muscles or nerves? But putting aside the *primâ facie* improbability of such an extraordinary and unsymmetrical arrangement of muscular bands, such a view as to their nature seems absolutely negatived by the fact of their undulating course, and their situation in the midst of a structure which would be disturbed and destroyed by their action. Then, again, with regard to the other view, which seems to find most favour with SCHNEIDER*, that these bands belong to the nervous system, we are met by the fact that, according to my measurements, they are often three times as broad as the largest nerve-fibre I could find issuing from a ganglion-cell in connexion with the œsophageal ring. In addition to this there is the difficulty of their asymmetrical distribution, which seems quite inexplicable on the supposition of their being nerves, though it can be smoothed over to a certain extent if we regard these structures as transverse vessels simply destined to bring the dorsal and ventral median lines into contact with one another. If this were their principal office, we can imagine that it might be, to a certain extent, immaterial whether the connecting vessels traversed the left or the right half of the body, or were distributed unequally on the two sides. Then comes the puzzling question, what can be the use of vessels to establish a communication between what appear to be two solid cords? And in reply I can only again refer to the impression which I have frequently been inclined to adopt, that in some species the median lines are traversed by a lacunar canal, and at the same time deplore the difficulties besetting the solution of this question. SCHNEIDER states that these vessels have a reddish colour in *A. megalocephala*; this I suppose must have been seen in the fresh animals before immersion in spirits of wine, in which condition, owing to their poisonous effects upon me, I have never been able to examine them. The colour was in all probability due to the fluid contained within the vessels. I have looked for similar transverse vessels in many Nematoids, but have only found them in the two above named. SCHNEIDER, however, states that he has discovered them in *Heterakis vesicularis*, and many other minute Nematoids, though he has failed to recognize them in any species of the genera *Oxyuris* or *Strongylus*. Further investigation, both with regard to the connexions of these vessels, and to their prevalence amongst the Nematoids generally, would be most desirable.

---

* This may be most readily effected by maceration for about a week or ten days in dilute nitric acid. The muscles require to be removed with great care, in order not to injure the layer in which the vessels are contained.

---

* MÜLLER's Archiv, 1863, S. 10.

THE RESPIRATORY FUNCTION—HOW PERFORMED?

Amongst the lower Invertebrata it is a well-known fact that the function of respiration is effected by the most dissimilar means, and often by distinct processes working independently in the same animal towards the fulfilment of a similar end. We need not be surprised therefore if such is found to be the case amongst the Nematoids. It is, however, rather remarkable that cilia, which often (as first pointed out by Dr. SHARPEY[*]) play so important a part in the respiratory processes of the invertebrate animals, should never yet have been detected in any Nematoid either parasitic or free.

The function of respiration seems to be duplicate in its nature: one object which it fulfils in the animal economy being to secure a certain amount of oxidation of the tissues, and the other being the performance of a function of elimination, supplemental in its nature to the similar work effected by the two other great excretory organs, the kidneys and liver[†]. It may well be that the relative proportions of these two processes in different animals may be variable, since a greater activity of the eliminatory function —performed by organs howsoever named—might atone for an inefficient accomplishment of the process of oxidation. In many of the parasitic Nematoids, we can well imagine, from the situations in which they are found, that the very existence of organs destined to facilitate such a process of oxidation would only be productive of evil rather than good. And the facts revealed by the anatomy of these animals tend to support this *à priori* assumption. We meet with glandular structures and excretory organs in abundance, but with no trace of a special apparatus destined to secure an aëration of the tissues; such a function is, I believe, almost in abeyance in the parasitic Nematoids, whilst the glandular and eliminatory function is more than ordinarily developed.

---

[*] Cycl. of Anat. and Phys. vol. i. Art. *Cilia*.

[†] Even this process of oxidation appears to be in great part destined to perform a disintegrating function, and so may perhaps be looked upon as the first stage of a process of elimination. Dr. LIONEL BEALE says, "Oxidation seems to be connected rather with the disintegration or removal of *fully developed and worn-out tissue* than with the growth and multiplication of masses of germinal matter."—*On Inflammation*, Med. Times, 1865, vol. i. p. 594.

It seems absurd to imagine that the two longitudinal tubes, in connexion with the ventral pore in certain species of the genus *Ascaris*, could be destined to admit external fluids for the purpose of respiration. And even if all evidence were not opposed to this suggestion, a consideration of the more rudimentary condition of this apparatus, as met with in the genus *Strongylus* and so many other Nematoids, would of itself go far towards its refutation. Here we have undoubtedly to deal with an excretory glandular apparatus. No one could for a moment regard these structures as at all analogous to vessels destined alternately to receive and discharge an external fluid medium. I believe that in the *Trematoda* and *Tæniada* also, where similar, though often more developed systems exist, their function is in like manner one of a purely eliminatory kind, and I cannot therefore but look upon the name of "water-vascular" apparatus as a singularly inappropriate appellation for this system of vessels.

In those Nematoids in which this excretory system is most developed, where the vessels or tubes composing it are lodged in the lateral bands or developments from them, it may be, perhaps, that these cellular structures bear the relation to them of parenchyma to gland-ducts. It may be noticed also, that in the *Strongyli*, *Oxyurides*, and many free Nematoids in which this excretory apparatus exists in the more undeveloped condition of a ventral gland, its eliminatory function appears to be supplemented by the presence of almost similar glandular structures in connexion with the anus and vagina.

With regard to the integumental pores, they seem also to countenance the belief that the deep integumental layer is to a certain extent an excretory organ, and I am inclined to look upon them as a series of excretory channels in connexion with this structure, having a sort of distant analogy therefore with sudorific ducts. That such is their nature is to a certain extent countenanced by the fact of their extreme abundance in the *Trichocephali* and *Trichosomata*, in which no ventral gland or other modification of this excretory apparatus is to be met with; so that the function of these seems to be performed by the cellular bands and related integumental pores so universally met with in the animals of this group. Amongst the free Nematoids, too, the very species in which these integumental channels are met with in the most marked abundance, such as *Dorylaimus stagnalis* and *Leptosomatum figuratum*, are also those in which there is to be found no trace either of ventral, anal, or vaginal glands.

Amongst the free Nematoids we might expect to meet with some evidence of the performance of the aërating portion of the respiratory process, and I think this may be effected in part by means of the fluid so constantly observed in the alimentary canal of these animals, which is kept in almost perpetual movement by the rapid undulations of their bodies. As first observed by CARTER in his *Urolabes palustris**, and since witnessed by myself in *Dorylaimus stagnalis*, there seems to be a more special provision for a respiratory process of this nature amongst the *Dorylaimi*, somewhat similar to what occurs amongst the *Naïdinæ*. The posterior portion of the intestine presents a modified structure in these species, which in all probability has something to do with the process alluded to; in *Dorylaimus stagnalis*, for instance, for a distance of $\frac{1}{50}''$ of an inch it is almost devoid of the thick lining of hepatic cells met with throughout the rest of its extent (Plate XXVIII. fig. 4, *a*). In individuals of this species I have seen sudden jets of clear fluid expelled, by contraction of the intestine, through the anal cleft, in a periodical manner, at intervals of four or five minutes. After its expulsion the anal cleft seems to close immediately with valve-like rapidity, and how the fluid enters for the next discharge is rather obscure. In the *Naïdinæ* the process is perfectly simple; the fluid is introduced through the anal aperture by the agency of powerful cilia lining the whole posterior portion of the intestine, and is as distinctly expelled by intestinal contraction. The most careful search, however, has revealed no trace of the presence of cilia in the *Dorylaimi*. It is true, they may be so small as to have escaped recognition.

In the genera *Tylenchus*, *Plectus*, *Aphelenchus*, and *Cephalobus*, the ventral gland is in a somewhat rudimentary condition, and the integumental pores seem wanting altogether; it therefore seems possible that the superadded lateral vessels met with in these animals may in some way be connected with the function of respiration†.

ORGANS OF GENERATION.

I have comparatively little to say on this subject. There is no particular discrepancy in the accounts given of these structures by different observers; their general form and arrangement is pretty well known, and nothing more was likely to be learned from them which would be of material assistance in determining the affinities of the Nematoids. I have therefore not made these organs the subject of any systematic investigation, and in addition to pointing out their prevailing form in the free Nematoids, have only a few scattered facts to mention under this head.

In the "Monograph on the Anguillulidæ," I called particular attention to the fact of the great uniformity in the disposition of these organs amongst the free Nematoids, and stated that for this amongst other reasons it seemed to me desirable to locate them in a family altogether distinct from those into which the parasitic species are divided, since in only two or three exceptional parasitic species is the same arrangement met with.

The form and position of these organs‡, in both the male and female *Dorylaimus stagnalis*, I have represented in Plate XXVIII. figs. 1 & 2, and this may be considered as

---

* Really *Dorylaimus palustris*. *Vide* Ann. of Nat. Hist. Ser. 3, vol. iv. p. 33, pl. 2, fig. 7.

† *Vide* note, p. 619.

‡ For the sake of clearness they have been drawn in a somewhat diagrammatic manner.

their typical condition in the *Anguillulidæ.* We find in the female a transverse vulva opening near the middle of the body in the ventral region, with a short vagina leading into a symmetrical, double uterus whose cornua extend on either side; these uteri are separated by constricted portions from narrower oviducts, whilst these in turn communicate with reflexed ovarian tubes. The oviduct has scarcely ever a greater proportional length than is represented in the figure, and is often proportionally much wider, as may be seen in the members of the genus *Plectus* (Plate XXVIII. fig. 15). We never meet with the long filiform ovaries so characteristic of many of the parasitic Nematoids. In a certain number of the *Anguillulidæ*, however, the vulva is situated near the commencement of the posterior third of the body, as in the genera *Monhystera*, *Tylenchus*, &c., and in these cases the posterior uterine segment remains undeveloped, whilst the anterior half which does exist preserves the characters above described. In the male there are two somewhat elongated ovoid sacs or testicles, connected by narrow canals with the commencement of a simple tube or vas deferens, which opens externally, together with the intestine, at the anal cleft. On either side of its termination, and capable of being protruded through the anal cleft, are two spicules, equal in size and of a horny nature. These spicules may be either solitary, or provided with one, two, or even four accessory pieces. In two species, *Monhystera ambigua* and *M. disjuncta*, I have seen the genital tube opening separately from, and anterior to the anus. In the former I was also unable to detect spicules of any kind, whilst in the latter, curiously enough, they were in their usual situation, and therefore quite separate from the termination of the genital duct[*]. In certain genera, such as *Rhabditis* and *Monhystera*, the male genital tube appears to be connected with only one testicle, which is separated by a constriction from the efferent duct[†].

The spicules amongst the free Nematoids are not enclosed in a distinct sheath, such as we find amongst the *Ascarides* and many other parasitic Nematoids. In the genus *Ascaris* two equal spicules, each enclosed in a firm thick-walled sheath, are generally met with, one on each side of the body (Plate XXV. fig. 7 *n*, *o*), but in *Ascaris lumbricoides* I have found them very unequal in size and situated close to one another (Plate XXIII. fig. 4).

The structure of the genital organs met with in the Guineaworm is, so far as I have seen, quite unique amongst the Nematoids, though it seems more easy to connect it with an extreme modification of organs such as are met with amongst the free Nematoids, than with anything similar amongst others of the parasitic species. The histological differentiation of its tissues, and the developement in it of well-marked elastic tissue, similar to what is met with in the vascular system of higher animals, is an interesting fact[‡].

The spermatozoa in the parasitic Nematoids, so far as we know at present, are generally motionless, spherical, or ovoidal bodies of a cellular nature, and as such they also exist most frequently in the free species. Thus they are very small vesicular bodies in *Theristus acer* (Plate XXVIII. fig. 22), larger in *Comesoma vulgaris* (Plate XXVIII. fig. 23), much larger ovoid bodies of the same kind in *Monhystera ambigua*, $\frac{1}{625}''$ in diameter (Plate XXVIII. fig. 24), and small pyriform corpuscles in *Enoplus communis* (Plate XXVIII. fig. 25).

---

[*] See, for this and various modifications in the form of spicules, "Monograph on Anguillulidæ," Trans. of Linn. Soc. pls. 9–13.

[†] Well represented by DAVAINE in Recherches sur l'Anguillule du blé niellé, pl. 3. fig. 1.

[‡] Trans. of Linn. Soc. vol. xxiv. p. 118, pl. 22, figs. 34 & 37.

In *Rhabditis marina* I have seen the spermatozoa presenting totally different characters; they appeared as short cylindrical bodies $\frac{1}{5000}''$ long (Plate XXVIII. fig. 13), having moreover a slowly oscillating movement, which was seen to continue for more than twenty-four hours. In *Monhystera disjuncta* the spermatozoa were linear bodies $\frac{1}{1000}''$ in length (Plate XXVIII. fig. 26), having a slowly serpentine movement. The spermatozoa of *Dorylaimus stagnalis* are most frequently met with as bright highly refractive bodies, enclosed within a hyaline vesicle, though a later stage of evolution seems to convert them into free filamentous bodies $\frac{1}{1000}''$ long, and narrower at the extremities than in the middle (Plate XXVIII. figs. 8 & 9). It seems probable that the spermatozoa of different species are not always in the same stage of development when emitted from the male; in some cases they appear to continue their development within the female organs of generation, before coming into contact with the ova.

The only Nematoids I have seen in *actu coitus* were specimens of *Cephalobus persegnis*; the male was coiled around, at right angles to the female, in the same fashion as was observed by DUGÈS with specimens of *Anguillula aceti*, and as others have noticed in certain of the parasitic species.

There seems to be no fixed period of the year which may more especially be considered as the breeding-season of these animals; in spring, summer, autumn, and mid-winter alike I have found amongst the free species females containing impregnated ova. In the majority of these animals, too, the ova are very large in proportion to the size of the body, and few in number—in both respects presenting a striking contrast to what is usually met with amongst the parasitic forms. The two divisions of this order agree, however, in the fact that, whilst the majority of the species are oviparous, the remainder are viviparous, bringing forth active young, presenting in a miniature form the external characters of the adult animals.

DEVELOPMENT.

Under this head I have nothing new to say concerning the early development of the ovarian cells and spermatozoa, or the actual process of fecundation in the Nematoids. This has been treated of most fully with reference to the parasitic species by NELSON, BISCHOFF, LEUCKART, MEISSNER, and ALLEN THOMPSON, and as it occurs amongst the free Nematoids by DAVAINE and CARTER; and for the results of their investigations I must refer to the various periodicals in which these observations were recorded. To have gone over this ground, and to have endeavoured to reconcile discrepancies at present existing in the accounts given by these various anatomists, would of itself have been an investigation demanding the utmost care and patience; and although it constitutes a subject replete with interest, I have not had sufficient time at my disposal to undertake it.

All are agreed, however, as to the direct method of development, by which the entire fecundated yelk-mass, after undergoing the well-known process of segmentation, is converted into the form of the future animal, either without, or whilst still enclosed within the body of its parent. Further than this, however, almost nothing is known concerning the after stages of development in which, by the development and differentiation of its internal organs, it attains to the typical form of its species; and this may be accounted for in a measure by the fact that, with one recent exception only, the complete and entire life-history of no other parasitic Nematoid has been fully revealed*. A gap remains in the history of most between the period of their emergence from the egg, and the time when they are usually met with as sexually mature individuals within the bodies of their various hosts. Whether during this intervening period they are to be met with in other primary intermediate hosts, in a non-sexual condition, such as we are familiar with in *Trichina spiralis* and the species included under the name of *Filaria piscium*, or whether during the course of their existence they are, as a rule, parasitic only within a single animal, is a question which at present we are unable to answer; and unfortunately the latest and most distinguished writer upon helminthology in this country has made such opposing and contradictory statements† as to leave us entirely in the dark as to the real nature of his views on this question‡. It is, however, amatter of perfect certainty as regards the free Nematoids that they undergo their development at once in the regions where they are born, in association with their parents, and other kindred species, young and old: generation succeeding generation in the same external habitat, and parasitism neither entering into nor being required by them in any stage of their simple life-history. In these therefore the whole process of development might be studied, provided the young animals could be kept alive and under observation during the period necessary for this investigation. I have not had much time to devote to this portion of the subject, and consequently have only a few rather unconnected details to bring forward, partly concerning the parasitic and partly concerning the free species.

---

* Since this was written Professor LEUCKART has published an admirable paper "On the Developmental History of the Nematoid Worms" (Archiv für Wissensch. Heilkunde, Band II. pp. 195–235, and translated in the Annals and Magazine of Natural History, May and June, 1866), in which he has contributed very largely to our stock of knowledge on this subject. He has ascertained the complete life-history of many species of parasitic Nematoids, and gives numerous details concerning developmental modifications.

† Compare opinion expressed at p. 308 with that at p. 313 of Dr. COBBOLD's 'Entozoa,' 1864.

‡ Professor LEUCKART (*loc. cit.*) has now definitely ascertained that both these methods of development exist amongst the Nematoids. A synopsis of the different kinds of life-histories met with amongst these animals is given by him in the Bull. de l'Acad. Roy. des Sc. Belg., No. 3, 1866, p. 208. The most remarkable history yet revealed is that of *Ascaris nigrovenosa*. It has been shown by LEUCKART and MECZNIKOW that the young of this animal, after passing from the rectum of the frog into damp earth or mud, grow rapidly, and actually develope in the course of a few days, whilst still in this external medium, into *sexually mature* animals. Young, differing somewhat in external characters from their parents, are soon produced, and these attain merely a certain stage of development whilst in the moist earth, arriving at sexual maturity only after they have become parasites, and are ensconced in the lung of the frog. Here, as Professor LEUCKART remarks, we meet with "no simple alternation of the conditions of life, but with an alternate sequence of free and parasitic generations. And what is most wonderful, *both these generations are sexually developed*, both are produced from ova. Here, therefore, we have nothing to do with an ordinary alternation of generations, such as occurs, for example, in the *Distomeæ*, but with a process hitherto almost unheard of in the animal kingdom, and which calls for our consideration the more because we are accustomed to regard the sexual development of an animal not merely as the sign of its perfect maturity, but also as the criterion of specific individuality." The life-history of this animal will be more marvellous still if Professor LEUCKART's supposition be correct (and it seems the most probable one) as to the young of the parasitic form being produced by a process of *agamogenesis*. No parasitic males of this species have ever yet been met with.

In a former paper on the Guineaworm* I alluded to the various accounts that had been given concerning the anus and the termination of the intestine in the young contained within this animal. Amongst others I mentioned the description which CARTER had given of the intestine terminating "at the root of the tail," near what I have described as lateral saccules and he as a gland. I had seen another disposition of the intestine so plainly that I was inclined to believe CARTER must have been mistaken; and it did not occur to me that the discrepancy in our observations might be fully accounted for by the fact of our having examined young animals at different stages of their development. Now, however, I feel assured that this is the most probable explanation of the former discordance in our views, since in three or four Guineaworms of different sizes which I have since examined, I have found a difference in the degree of development presented by their contained young; and in one animal I found them in a more advanced stage than I had ever before seen, displaying the intestine communicating with the exterior by an anal orifice in the very situation indicated by CARTER—that is to say, slightly above the level of the lateral sacculi (Plate XXVII. fig. 22, *a*). Thus the young which I had before examined and figured, in which the intestine ended cæcally, were less mature individuals, and so exemplified what appears to be the usual course in the development of the intestinal canal in higher members of the animal kingdom. It exists first in the form of a cæcal tube which gradually elongates, so as to approximate and ultimately unite with an anal orifice commencing independently as an infolding of the parietes of the body. That the young I first examined were less mature is also indicated by the fact that the measurements I gave of them were below those given of the young *Dracunculi* by several other observers. In these last more developed animals in which I have been enabled to detect the anal orifice, I also recognized rudimentary conditions of the two head papillæ, and, more interesting still, discovered what has not yet been detected in the adult animal, in the form of a distinct channel through the integument in the ventral region of the body, about $\frac{1}{300}''$ from its anterior extremity (Plate XXVII. fig. 24, *a*). May not this be the commencement of one of the forms of the ventral excretory apparatus met with in the Nematoids? Whether, however, it is the outlet of a future rudimentary saccule, or of two longitudinal vessels which are to exist in the lateral regions of the body, cannot be said. In the adult *Dracunculus* I have now recognized at a distance of $\frac{1}{285}''$ from the posterior extremity of the body two large caudal pores, apparently homologous with what are also seen to exist in the caudal regions of the *Ascarides* and so many other Nematoids (Plate XXVII. figs. 20, *c* & 21). And what I have described in the young of this animal as "lateral sacculi," I now suspect may be the early representatives of these lateral pores in the adult. The protrusions which are seen to exist in the place of these sacculi in some individuals are, I believe, due to a complete or partial extroversion of the walls of the sacculi. The proportionate size of these structures, as existing in the young, is certainly very large as compared with the pores in the adult; but if the sacculi are not to be considered their representatives, then we must look upon them as bodies altogether anomalous; whilst if they are so considered, we may expect to find the same structures more or less developed in the young of many other Nematoids. The differences in the relative position of anus, pores, and posterior extremity, as met with in young and old specimens of *Dracunculus*, is nothing more than might be expected, considering the enormous development attained by the adult, and the obviously wasted condition in it of the very elongated filiform posterior extremity existing in the young animal.

---

* Trans. of Linn. Soc. vol. xxiv. p. 122.

As I have stated elsewhere*, I am strongly inclined to believe that the Guineaworm was originally a free Nematoid, which, having obtained a direct entrance into the human body through the skin, attains an enormous size in the subcutaneous tissue. In the same place I pointed out, however, reasons why it could not, as CARTER imagined, be identical with his *Urolabes palustris*. The principal anatomical reasons lending support to the view of its being an enormously developed free Nematoid, are the following:—it has a very wide lateral intermuscular space, but no development whatever answering to the lateral band (Plate XXV. fig. 14, *f*), and, so far as we at present know, this is the case with no other parasitic species, though it is by no means uncommon amongst the free Nematoids for all traces of these structures to be absent†; the form of the young Guineaworms with their attenuated filiform extremities agrees closely enough with what is of most common occurrence amongst the free species, whilst if it exists at all amongst the parasitic forms, it must be a matter of the greatest rarity, since the only recorded instance of any approach to such a length and tenuity of the body posterior to the anus that I am aware of is in *Passalurus ambiguus*‡; and finally, so far as yet ascertained, the symmetrical condition of the genital organs, combined with the extreme shortness of the ovarian tubes, is a condition which, so far as I am aware, can only be paralleled amongst the *Anguillulidæ*. After further careful search I have still failed to find any trace of vulva or vagina, and am moreover still inclined to believe, for the various reasons stated in my memoir on this animal §, that a resort to the method of *agamogenesis* to account for the production of its countless young, is not only most in accordance with what we know of the history of this animal whilst in the human body, but also most consistent with the fact of the existence of young in the genital tube in all stages of growth, from the smallest germ upwards, at periods when the parent must have been actually within the cellular tissue of the human body for no less than eight, nine, or even more months[*].

---

* Trans. of Linn. Soc. vol. xxv. p. 126.

† Or, at all events, unrecognizable.

‡ *Oxyuris ambigua* of RUDOLPHI.

§ Trans. of Linn. Soc. vol. xxiv. p. 126.

In all the species of the genus *Dorylaimus*, before the animals have attained their full adult size, a reserve spear may always be observed imbedded in the anterior portion of the œsophagus, just posterior to the one *in situ* and slightly larger than it. This reserve spear seems to have no special connexions of any kind; it appears to be simply lodged in the substance of the œsophagus, and not even a containing sac can be detected. In the progress of growth of the animal the reserve spear gradually approximates to the position occupied by the other, and at last displaces it, as the permanent tooth supplants its temporary predecessor. What causes the reserve spear to rise, or how the movement is effected, I am quite unable to say. Neither do I know how many times a spear is thus displaced during the progress of the animal towards maturity. Being of a horny nature and cylindrical in form, it is perhaps itself incapable of growth, and therefore spears of successively larger size are produced, to keep pace with the increasing dimensions of the animal.

From what I have seen of the anatomy of that form of the so-called *Filaria piscium* infesting the common Haddock, I am quite convinced that it really is most closely allied to *A. osculata* and *A. spiculigera*, which should all be placed, if not under a new generic name, certainly apart as a distinct subgenus. At the same time that I obtained the encysted Nematoids from beneath the peritoneal membrane of the Haddocks, I also dissected a mackerel, and having found one similar encysted animal entangled amongst its pyloric cæca, I then opened the intestinal canal, and found within it a single Nematoid entirely free and unencysted. This was half as large again as the largest of the animals found beneath the peritoneal membrane, though when submitted to the microscope it was found to be a more highly developed individual of the same species, and quite devoid of the membranous sheath-like covering with which the others were closely enveloped. Although this animal did not exhibit the three head lobes at all plainly, the four papillæ usually situated on them were distinct. The development of the lobes is therefore probably characteristic of a later period of the animal's growth. The genital organs, if present, must still have been in a very rudimentary condition. How are we to suppose this animal gained access to the intestine of the mackerel? It seems probable that this occurred either owing to the mackerel having swallowed some smaller fish in which the Nematoid existed in an encysted state (in which case we might expect the mackerel to be the proper host of this species in its mature condition), or else we must have recourse to the more improbable alternative, that one of the encysted individuals, previously to be found beneath the peritoneal membrane, had contrived in some way to penetrate the wall of the intestine in order to gain that situation requisite for its future development.

The development of the genital organs does not seem to take place very early. Spe-

---

[*] Professor LEUCKART has accepted this doctrine, since it seems most in harmony with anatomical facts, and also best explains certain peculiarities in the life-history of this parasite.

cimens of free Nematoids may frequently be seen which have attained more than half the usual adult dimensions, with well-formed tissues and a fully developed alimentary canal, though still in an asexual condition and presenting no trace of genital organs. What is the order of development of these organs in the male, and how soon the spicules appear I am unable to say, though I have been able to notice a few facts concerning the genesis of this system in the female. Its first rudiments consist of a small mass of indifferent tissue lying within the parietes of the body, opposite the future situation of the vulva, and to a certain extent pressing upon the alimentary canal*; and, as I have seen in species of the genus *Mononchus*, this gradually increases in size, more especially in a longitudinal direction, its central portion growing outwards so as to come into relation with a gradually formed aperture through the integument—the future vulva—whilst on either side it is developed into an elongated pyriform mass. So far only have I traced this process of development; the remaining steps consisting, in all probability, in the formation, on each side, of an internal cavity in what was at first a mass of solid homogeneous tissue; the continued growth and separation of the parts into ovary, oviduct, and uterus; and the final differentiation of tissue by which the textures proper to each segment are produced—these stages though easily imagined have yet to be observed.

With regard to the duration of life in the parasitic Nematoids we have, I believe, no definite knowledge; great variation in this respect would doubtless be met with in different species. Amongst the free forms, however, we do know, as pointed out by M. Davaine†, that the duration of the *active* life of *Tylenchus tritici* can only be from nine to ten months. In the animals of this species, too, the females die after the production of a single batch of ova‡; probably this, however, may simply be due to the necessities of their mode of existence, which is so exceptional in its nature as to render any data we may possess concerning these animals of little value for the determination either of the period of existence, or of the number of batches of ova produced by the free Nematoids generally.

POWERS OF REPAIR AND TENACITY OF LIFE.

Almost all the observations I have now to make refer to the *Anguillulidæ*, since what we know on these subjects concerning the parasitic Nematoids may be stated in a very few words.

With regard to the powers of repair in the parasitic species I believe absolutely nothing is known, but some remarkable statements have been made concerning their tenacity of life, and concerning the conditions under which development of their ova will proceed. Thus Nelson and Allen Thompson have best been able to study the development of the ova of *Ascaris mystax* whilst the animals in which they were contained were immersed in oil of turpentine; whilst Professor AITKEN says he has "seen the development of the embryo proceed in spirits of wine for about three weeks before signs of vitality had ceased." In certain species of *Ascaris* it has been shown by many experiments that the ova remain in fluid occasionally for more than twelve months before they begin to exhibit any active signs of development. Many observations also tend to show that the majority of young and immature Nematoids are enabled to survive under circumstances which rapidly prove fatal to the adults. Thus, speaking of *Trichina spiralis*, Dr. COBBOLD* writes, "M. DAVAINE kept the larvæ alive in water for a month, but the adult worms perished in cold water in about an hour. Under ordinary circumstances DAVAINE'S observations lead us to conclude that the adult worms do not survive their hosts above six hours, but the larvæ will live for a long time in flesh which has already undergone putrefaction." Some of the statements made concerning the tenacity of life in the adult animals are so marvellous as to appear incredible; thus OWEN† states, "a Nematoid worm has been seen to exhibit strong contortions—evident vital motions—after having been subjected above an hour to the temperature of boiling water with a codfish which it infested." Whilst according to Dr. AITKEN‡, MIRAM has seen specimens of *Ascaris acus* from the pike "become dry, and remain sticking to a board, where they would revive again by being placed in water; and in some instances they would move a part of the body which had imbibed the fluid, whilst the remaining part continued shrivelled up and adherent immoveably to the board;" and he further adds, "I have seen the very same results in the *Ascaris* which infest the peritoneal covering of the mackerel." With regard to such powers possessed by these animals I can myself say nothing.

---

* This condition may be well seen in the young of *Tylenchus* (*Vibrio*) *tritici*, where it forms what appears a clear space, with a slight displacement of the intestine opposite it, which from its shape has been termed the "lunule." The rudiments of the genital organs are seen unusually early in this species.

† Recherches sur l'Anguillule du blé niellé, Paris, 1857, p. 38.

‡ This may be considered as the most prolific of the free Nematoids; in this respect, indeed, as well as in the nature of its habitat, it approximates closely to its more strictly parasitic kindred.

Passing now to the *Anguillulidæ*, I may state as the result of many experiments with these, that the power they possess of repairing injuries seems very low. I have cut off portions of the posterior extremity of the body of *Enoplus communis*, and though I have watched the animal for days after could never recognize any attempt at repair. And, as a general rule, when the bodies of any of the larger marine species are severed, both fragments of the body will continue to move for from three to five days, though during this time neither of the cut extremities shows the slightest signs of repair. For the last day or two the fragments move only when irritated, and finally they cease to respond even when roughly touched§. Within twenty-four hours of this time their bodies may be seen swarming with myriads of minute monads, to which the next day may be added larger infusory animalcules; together, these proceed rapidly with the work of demolition, and in the course of a few days leave only the chitinous integumentary sheath of the Nematoid as the remnant of their feast.

---

* Entozoa, 1864, p. 34.

† Lect. on Comp. Anat. 1855, p. 116.

‡ Science and Practice of Medicine, vol. ii. p. 126.

§ It seems possible that in some cases the anterior half of the body may survive much longer from a consideration of the following facts. On April 5, 1864, I found in a wide-mouthed bottle containing salt water and a very small quantity of a filamentous green seaweed, the anterior half of a specimen of *Oncholaimus vulgaris*, quite active in its movements, though presenting no traces of repair. It seems almost certain that the injury to this animal must have been done on or before the 24th of the preceding month (March), since the water and weed were put into the bottle on that day, and had not been interfered with in the meanwhile. Neither were there any larger animals in the bottle capable of biting the *Oncholaimus* in two.

The revival of animals after complete desiccation was first observed amongst the Rotifera by LEEUWENHOEK in 1701, and his observations were subsequently repeated by many other naturalists during the next half century, the principal of whom were HILL, BAKER, FONTANA, GÖZÉ, CORTI, OTTO MÜLLER, and the ABBÉ SPALLANZANI. The discovery, by NEEDHAM, in 1743 of the young Anguillulæ in what appeared to be diseased grains of wheat*, added another animal to the list of those possessing this remarkable power of *reviviscence* after prolonged periods of desiccation; and very shortly after this the number was still further increased by SPALLANZANI discovering that, in addition to the Rotifera in tufts of moss, there were certain Anguillulæ and arachnidal animals ("Sloths") found in the same situation, all of which were endowed with a similar tenacity of life.

One of the most interesting facts that has yet been made known concerning the so-called *Vibrio tritici* was ascertained by BAKER. He discovered that some of these animals contained in diseased wheat, given to him by NEEDHAM in 1744, still possessed the power of resuming all their vital manifestations, after immersion in water, in 1771; that is to say, after a period of twenty-seven years†. This is the longest period on record, and several observers have failed to restore them after much shorter intervals. Thus with wheat of a certain year's growth, BAUER‡ could not revive these animals after five years and eight months; whilst with that of another year he met with the same failure after six years and one month. My friend Mr. W. H. INCE tells me that he has seen them revive from specimens of wheat which had been kept "about twenty years." The varying periods during which these Nematoids retain this power of reviviscence in all probability depends very much upon the manner in which the "galls" have been preserved during the interval; much in the same way as the length of time that seeds are capable of retaining their power of germination, is greatly influenced by the method of their preservation—by variations in their hygrometrical condition, and degree of exposure to the air.

---

* The Nematoid (*Tylenchus tritici*) producing this disease of wheat, known as "purples" or "ear-cockle," is not contained in a real seed but in a gall-like growth replacing this. For further particulars on this subject see DAVAINE's 'Recherches sur l'Anguillule du blé niellé,' p. 20, and the "Monograph on the Anguillulidæ," Trans. of Linn. Soc. vol. xxv. p. 87.

† Lettre de NEEDHAM en réponse au mémoire de Roffredi, dans 'Journ. de Physiq.' t. v. p. 227, 1775. At one time SPALLANZANI believed that these were not real animals, but merely "filets allongés et mis en mouvement par le fluide qui les pénètre" (Nouv. Recherch. sur les découv. Microscop. &c., Annot. par Needham, part 1. p. 25, Paris, 1769); in this belief he was for a time followed by NEEDHAM. Both OKEN and RUDOLPHI (Grundr. der Physiolog. 8vo, 1821–27) deny the fact of the revival of animals after desiccation, whilst BORY DE SAINT-VINCENT and DUGÈS deny its occurrence in the *Vibrio tritici*. Even DIESING, writing as late as 1851, makes the following statement on this subject:—"Animalcula exsiccata, iterum humectata post annos reviviscere narrant cel. BAUER et HENSLOW, phænomenon rectius forsan motu *moleculari explicandum*" (Syst. Helminth. t. ii. p. 132). And even amongst those who admit the fact of the reality of the powers possessed by these animals of recovering after periods of desiccation, most various statements have been made by recent writers; thus COBBOLD states that they are capable of recovering after "two or three years" of desiccation, whilst Professor AITKEN (Sc. and Prac. of Med. 1863, vol. iii. p. 126) even puts the period as low as from "four to seven days."

‡ Philosophical Transactions, 1822.

It was first observed by SPALLANZANI that one of the essential conditions for the revival of the Rotifers and Anguillules found in tufts of moss was, that their period of desiccation should either be passed in these tufts, or else that during the same time their bodies should be more or less covered with sand[*]. His explanation of this fact was that the access of air exercised a prejudicial influence upon the delicate structures of these animals. The fact is quite in accordance with my own observations, and as regards its explanation, I am able to offer nothing more satisfactory than that advanced by SPALLANZANI. He alternately dried and moistened the same animalcules twelve times with similar results, except that the number of the revivers was successively smaller each time, but after the sixteenth moistening he failed to restore any of them to life[†].

Since SPALLANZANI's time the most interesting experiments concerning the power of reviviscence in the Anguillulidæ have been made by M. DAVAINE[‡] and by MM. DOYÈRE and GAVARRET[§]. I shall briefly notice some of the principal results arrived at by these experimenters before detailing my own observations on this subject.

DAVAINE ascertained that the time of saturation in water necessary for the recovery of the young of *Tylenchus tritici*, was not directly proportional either to the length of their period of desiccation, or even to the actual degree of desiccation to which they had been submitted. With regard to the length of the period of desiccation he adds, "il y a, sous ce rapport, moins de différence entre les larves d'un an et celles de quatre ans, qu'entre les larves d'un mois et celles d'un an." To ascertain the influence of the degree of desiccation upon the time necessary for their recovery he made the following experiments. Larvæ three years old were taken, and placed under the receiver of an air-pump, together with a large capsule containing concentrated sulphuric acid to absorb all aqueous vapour; the air was then exhausted as completely as possible, and the animals allowed to remain *in vacuo* for five days. Then when withdrawn and immersed in pure water, most of them resumed their activity and vital manifestations after a period of three hours. Subsequent experiments convinced him that larvæ, varying from one to three years old, invariably recovered as quickly after they had been completely desiccated by a sojourn of four days in a vacuum, as did others of the same age that had merely been exposed to the air for a similar period. In grains which have been gathered only a few days the animals may be revived in less than an hour; in those which have been kept four years in not less than ten, fifteen, or twenty hours. It is quite improbable, however, that these last could be so dry as fresh grains which had been preserved in a vacuum with sulphuric acid for four days, and whose contained young even after this process may be revived in less than an hour. The time during which they are allowed to remain active considerably influences their future power of reviviscence; thus, DAVAINE finds, "Après un mois du séjour dans l'eau, la plupart des anguillules desséchées ont encore la faculté de revenir à la vie. Passé ce temps, elles perdent assez promptement cette faculté. Aussi lorsqu'on met dix jours d'intervalle entre chaque dessication nouvelle, dès la quatrième revivification l'on voit le nombre de celles qui restent mortes augmenter rapidement. La durée du temps pendant lequel on garde ces animaux en état de dessication a peu d'influence sur ce résultat, qui dépend en grande partie de *la durée de la vie active.*" DAVAINE insists upon the fact that organic matter of any kind undergoing decomposition in the water in which desiccated animals are immersed, will absolutely prevent their exhibiting any movements or signs of life. They remain stiff, straight, and motionless, though not in reality dead; and from other experiments concerning the noxious properties of even the minutest quantity of ammonia mixed with the fluid containing these animals, he supposes that the deleterious influence of decomposing organic matter may in reality be due to the evolution of minute quantities of ammonia. For interesting details on this subject, and also on the influence of solutions of various poisonous and narcotic alkaloids, I must refer to M. DAVAINE'S interesting memoir. He also dwells upon what I am able to confirm, viz., the fact that the remarkable powers possessed by the young are not shared by the adult *Tylenchus tritici*, which does not exhibit any very well-marked tenacity of life. As I shall point out afterwards, however, this is quite exceptional, and is in all probability due to the method of existence of this animal, since in other species of the genus *Tylenchus* both old and young are similarly endowed in this respect. Elsewhere* M. DAVAINE having become aware of the fact that all the Anguillulidæ do not possess this same tenacity of life, made a general statement on the subject which comes very near to the truth; he thinks that those species which are constantly submerged do not possess this property of recovering even after short periods of desiccation, whilst it is possessed by others, "qui vivent dans les lieux exposés aux alternatives de sécheresse et d'humidité." This is a considerable advance upon the popular opinion, which has hitherto regarded all the free Nematoids as endowed with the same remarkable tenacity of life; although in the right direction, it is, however, too sweeping a generalization.

---

[*] Tracts on the Nat. Hist. of Anim. and Veget. Transl. by DALYELL, vol. ii. (ed. 2) p. 129 *et seq.*

[†] OWEN's Lect. on Comp. Anat. 2nd ed. p. 54.

[‡] Recherches sur l'Anguillule du blé niellé, 1859, pp. 39–61.

[§] Ann. des Sc. Nat. 4^{me} sér. t. xi. 1859, p. 319.

The experiments which were conducted in concert by MM. DOYÈRE and GAVARRET upon the degree of tenacity of life of the Rotiferæ and Anguillulidæ found in tufts of moss are of the greatest interest, and the results of their inquiries may be accepted with all the more satisfaction, from the very evident care and caution with which these experiments were conducted. Their paper should be studied by all interested in this question, so startling are its results, and so opposed to all ordinary biological data. I cannot refrain from quoting here the results of one carefully performed series of experiments, instituted to ascertain the power of resisting simple desiccation at ordinary temperatures possessed by these animals. Their words are, "En résumé ces mousses étaient restées *soixante-sept* jours dans un armoire du cabinet de physique de la Faculté de Médecine (du 21 juin au 27 août), avaient subi pendant *deux* jours l'action de *l'air sec* (du 27 au 29 août), et pendant *cinquante et un* jours l'action du *vide sec* (du 29 août au 19 octobre); elles étaient si *complètement desséchées*, qu'en *quatre* jours d'exposition à la double influence du vide et de l'acide sulfurique (du 15 au 19 octobre) elles n'avaient rien perdu de leur poids; néanmoins *vingt-quatre heures de simple hydration* ont suffi pour rendre *toute leur activité* aux rotifères, aux tardigrades (*Emydium*, *Macrobiotus*), et aux anguillules de ces mousses" (*loc. cit.* p. 319). Unfortunately other interesting results arrived at concerning the influence of heat upon these previously desiccated animals refer to the two former varieties only, since no Anguillulidæ, either living or dead, were seen in these later experiments. The other animals recovered after being submitted for a few moments to a dry heat of more than 212° F. According to M. DAVAINE, however, the young of the *Vibrio tritici* completely lose their vitality when submitted in the same way to a dry heat of 160° F. Their power of resisting low temperatures is most remarkable, since he says they will recover their vital manifestations after being subjected to a temperature of 0° F. for eight or ten hours.

---

* Ann. des Sc. Nat. 4^{me} sér. x. 1858, p. 387.

So far as my own observations have gone at present, I find that amongst the *Anguillulidæ* this remarkable tenacity of life of which we have been speaking, is met with only amongst the representatives of four land and freshwater genera, *Tylenchus*, *Plectus*, *Aphelenchus*, and *Cephalobus*; whilst those of all the other genera excepting *Rhabditis*, marine as well as land and freshwater, are rather remarkable for the very opposite characteristic, they being incapable of recovery even after the shortest periods of desiccation*. Very many of the species of these four genera are found in earth, lichen, moss, or other situations in which they are exposed to constant vicissitudes of drought and moisture according to ever changing meteorological conditions, and in the possession of this power of resisting the effects of desiccation they exhibit the most admirable adaptation for neutralizing what would otherwise be the fatal influence of the varying condition of their environment. Their whole life-history must be a strange one, made up of periods of life and activity alternating with others of potential death —the two states bearing no definite relation to one another as regards duration, being altogether inconstant and variable, and succeeding one another under the influence of laws so remote, as to make the successions of active and passive existence in these animals almost a matter of chance. Doubtless they have a certain *definite span of active existence*, in which to go through the stages of development and growth, and provide for the continuation of their kind by the ordinary processes of reproduction. Whilst the sum total of these periods of active life, peculiar and necessary to the species, is in all probability pretty definite, the period of time over which its fragmentary existence may be extended is altogether variable and indefinite, owing to the uncertain length and number of the interpolated periods of desiccation and apparent death. Whilst we meet with this admirable adaptation to external conditions in the animals of these genera, there are many species of the genera *Mononchus* and *Dorylaimus* found in some of the same situations, which are nevertheless frail and incapable of resisting desiccation. Many species of the genus *Plectus* also are to be met with which do lead a constantly submerged existence, and to whom therefore this remarkable tenacity of life would not be a matter of so much importance. These facts show that M. DAVAINE'S conclusions on this subject were drawn from insufficient data.

---

* In connexion with this statement I would call attention to the fact that, when water is added to these animals in a state of desiccation, a deceptive appearance is produced which might mislead a hasty observer. The more or less rapid imbibition of fluid into the bodies of these animals produces a few momentary contractions of the body, which, though really due to purely physical causes, are sufficiently simulative of vital movements. I think it must have been movements of this kind which led OTTO MÜLLER (Anim. Infusor.) to assert that certain marine forms did possess the power of recovery after desiccation. If this is not the case, then his observations are quite irreconcileable with what I have myself seen.

An examination of tufts of moss from the roofs of houses* or from old walls, as well as of specimens of the yellow lichen, *Parmelia parietina*, from the same situations, has invariably revealed to me three principal kinds of animal occupants—specimens of Rotifers, of peculiarly slow-moving arachnidal *Tardigrada*†, and two or three different kinds of *Anguillulidæ*. Precisely the same varieties of animal life are spoken of as existing in the tufts of moss examined by SPALLANZANI, and also in those which were experimented upon by DOYÈRE and GAVARRET. Moreover I have found specimens of lichen brought from Sweden tenanted by just the same types. In all the specimens of moss and lichen of the kind above mentioned that I have examined, I have invariably found that the free Nematoids present were representatives of my two genera *Plectus* and *Aphelenchus*. It seems therefore highly probable that the so-called "Anguillulæ" of preceeding observers were also representatives of these genera. The specimens met with were of very different ages, many containing well-developed ova within them, and the property of reviviscence seems common to old and young alike. Possibly there may be a slight difference in the degree of tenacity of life enjoyed by the immature and the adult animals respectively, but, at all events, no notable difference exists, such as we have ascertained to be the case with *Tylenchus tritici*. After what has already been said, it would be useless for me to give further details concerning the powers of resisting the effects of prolonged and complete desiccation possessed by these animals whilst still in their natural habitat, whether this be sand, moss, or lichen, but I can add a few interesting facts concerning the extreme curtailment of this power when the animal is allowed to undergo the process of desiccation on a slip of glass, isolated from all other materials and thus freely exposed to the air; and also concerning the results of other experiments, made with free Nematoids not belonging to one of the four genera before named.

In submitting the animals to these tests, I was careful to select active uninjured individuals, which were then removed carefully on the point of a feather and placed on a clean slip of glass.

---

* Belonging to the genus *Tortula*: often found in hemispherical masses.

† For some particulars concerning the anatomy of these singular animals see Archiv für Microsk. Anat. erste Band, 1865.

After specimens of species belonging to either of the four genera *Tylenchus*, *Plectus*, *Cephalobus*, or *Aphelenchus* had been thus laid on the slip of glass, the time noted, and the animals submitted uncovered to the microscope, I found them lose their form and begin to shrivel only very slowly, and also that after the allotted period of exposure to the desiccating influence of the air was over and some water was added, this seemed to penetrate their bodies very slowly—the gradual process of redistension often occupying nearly thirty minutes before the animal was quite restored to its original form. The length of time required, however, depends upon and increases with the duration of the period of exposure, and, in almost all cases, after the animal has regained its habitual form it remains for a variable time perfectly still and motionless. In experiments* with *Plectus parietinus*, I have found that if the period of exposure has been from one to four or five hours, the perfect redistention of the body usually occurs in about twenty-five minutes, and then the slow bending movements which are the first evidences of returning activity may begin almost immediately afterwards. As a rule, after an exposure of forty-eight, or even thirty-six hours, the animals never recover at all. Exceptions, however, occur: thus, I once saw an animal recover after it had been exposed for five days, though in this case the recovery was proportionally slow, the animal not having completely resumed its natural appearance till four hours after the addition of water, and not having commenced its first slow movements till after the expiration of another two hours. Occasionally the animals do not recover after much shorter periods of exposure than that mentioned above, and sometimes the resumption of activity after the addition of water is much more speedy than usual; thus, in one instance, an animal which had been exposed and dry for twenty-one hours, was seen in full activity only eight minutes after the addition of water. So far as I have seen, young specimens are certainly not capable of resisting exposure better than, or even so well as adults.

When we remember the power these same animals possess of resisting prolonged and complete desiccation *in vacuo*, as shown by the experiments of MM. DOYÈRE and GAVARRET, it is most striking to find them succumbing in such short periods to the mere desiccating influence of the atmosphere upon their *uncovered* bodies. How can we explain this without imagining the direct contact of atmospheric air to have a deleterious influence upon their tissues?

With animals belonging to the genera *Chromadora*, *Enoplus*, *Monhystera*, *Leptosomatum*, *Mononchus*, *Dorylaimus*, and many others, the results have been almost uniform. I have never succeeded in restoring any of these animals after they have remained dry and motionless on glass for two minutes; many would not recover after one minute of such exposure, and with *Chromadora communis* I have rarely been able to revive specimens after even half a minute's exposure, dating from the time of the *cessation of movement in the drying animal* as seen under the microscope. All these animals shrivel more quickly than those of the other four genera when thus exposed; and when water is added its imbibition, instead of being slow and gradual, is almost instantaneous, giving rise to a few contractions and movements which are at first simulative of returning vital movements. But this temporary activity almost immediately subsides, and then, though watched for many hours after, no movements can ever be discerned.

---

* Temperature of room (summer) 70½° F.

The members of the genus *Rhabditis* seem to occupy a kind of intermediate position. Thus, I have succeeded in reviving some specimens after fifteen minutes' exposure on a slip of glass, but in the few trials I have made, have never succeeded in doing the same after they have been exposed for twice that time. In their anatomy, also, these animals are somewhat allied to those of the four genera above mentioned, and the nature of their habitats being much the same, this remarkable tenacity of life is useful to all alike.

It seems to me that the increased tenacity of life exhibited by the members of the four genera *Tylenchus*, *Aphelenchus*, *Plectus*, and *Cephalobus*, is partly connected with the power they possess of retaining their tissues in a moist condition for a longer time than the others, owing to the comparative, or even total absence in them of the integumental pores which appear to be present in most of the other species of free Nematoids. This view is supported by what I have just stated of the difference in the rapidity of imbibing fluid exhibited by desiccated animals belonging to these two classes, and is still further borne out by other observations tending the same way. Thus I have seen adult specimens of *Tylenchus tritici*, when immersed in strong glycerine, instead of shrivelling up almost immediately as the great majority of free Nematoids would do, continue to swim about for twenty minutes in this dense medium before any shrivelling of their bodies took place. Moreover, I have immersed them, as well as specimens of the genera *Plectus* and *Aphelenchus*, in a magenta colouring solution and taken them out of it after the same period alive and active, and with their bodies perfectly uncoloured save for a very short distance from mouth, anus, or vulva; whereas other species not belonging to one of these four genera would have had their whole bodies perfectly coloured, and have been dead in two or three minutes. *Plectus parietinus*, however, only resists the glycerine for a minute or so, though it may remain alive in the magenta solution for half an hour and then only have the anterior portion of its œsophagus coloured, together with the external parts of the rectum and vagina, and the narrow portions (Plate XXVIII. fig. 14, *l′*, *l′*) of the vessels in communication with the lateral cervical spaces[*].

This power can, however, be looked upon only as a mere accessory contributing to the greater hold on life possessed by these animals, as it fails to account for facts, when we take into consideration the prolonged periods of ordinary desiccation—to say nothing of absolute desiccation *in vacuo*—which these animals will undergo and still recover. It is not only that they have this power of resisting the effects of desiccation, but they are also capable of resisting the effects of many other agents which would speedily prove fatal to others of their kindred not similarly endowed. There seems to be some innate, though inscrutable difference in the intimate constitution of their tissues, into the nature of which we may never be enabled to penetrate, even with the most perfect instrument the optician could devise.

---

[*] It is this fact which makes me imagine that these spaces must be perforated, although I have been unable to detect apertures even with the highest magnifying powers. May not these vessels be homologous with the more abortive, lateral, excretory tubes of *Leptosomatum elongatum* (Trans. of Linn. Soc. vol. xxv. pl. 12. fig. 156), since we know for certain that the similar vessels of *Tylenchus tritici* terminate posteriorly in cæcal extremities?

ZOOLOGICAL POSITION AND AFFINITIES.

Having now pretty fully explained the anatomy of the Nematoids, we shall be able, with the aid of the many new facts revealed concerning their structure, to consider the question of their affinities and homologies with more chance of success than formerly, so that we may hope to throw some light upon this difficult subject. Hitherto, to those anatomists who penetrate beyond mere external form, the Nematoids have been regarded almost as an outlying group, having no definite relationship with other animals, and admitting only of a provisional location in the convenient though utterly artificial class Entozoa. In the first volume of his 'Elements of Comparative Anatomy' recently published, Professor HUXLEY has done much to elucidate the homologies of the "Annuloid" animals; and as well from the philosophic nature of his views as from the fact that he is the latest writer of note who has treated on the classification of the Animal Kingdom, it seems desirable for me briefly to refer to some of these views in order that we may be able more fully to appreciate the state of the question concerning the affinities of the Nematoids.

In his 'Lectures on General Natural History'* he divided the subkingdom ANNULOSA into two great divisions, the ARTICULATA or ARTHROPODA and the ANNULOIDA; including in the former division *Insecta*, *Myriapoda*, *Crustacea*, and *Arachnida*, whilst in the latter he placed *Annelida*, *Echinodermata*, and *Scolecida*—the latter being a name under which he still proposes to include the *Entozoa*, *Turbellariæ*, and *Rotiferæ*.

In the recently published work†, however, this classification is somewhat modified; since whilst acknowledging that "the members of the class *Annelida* present marked differences from all the Arthropoda, but resemble them in one important particular, and that is the arrangement of the nervous system, which constitutes a ganglionated double chain traversed at one point by the œsophagus," still he now thinks "that the resemblances between the *Annelida* and Arthropoda outweigh the differences, and that the characters of the nervous system and the frequently segmented body, with imperfect lateral appendages of the former, necessitate their assemblage with the Arthropoda into one great division or subkingdom of ANNULOSA."

Whilst laying little stress now upon the few resemblances of the Echinoderms and Scolecids to the Annelids, such as the occasional resemblance between their ciliated larvæ, and the possibility of the vessels of the Annelids being modified representatives of the water-vascular apparatus, he thinks there can be no doubt as to the many singular resemblances which unite the Scolecids and the Echinoderms together. And whilst partly admitting the difficulty of the different arrangement of the nervous system in these two classes, he says, speaking of the ambulacral system in the Echinoderms and the water-vascular system in the Scolecids, "It is impossible to compare these two systems of vessels without being struck by their similarity; each is a system of canals opening externally and ciliated within, and the circumstance that the two apparatuses are turned to different purposes in two distinct groups of the animal kingdom, seems to me no more to militate against their homology, than the respiratory function of the limbs of Phyllopod *Crustacea* militates against the homology of these limbs with the purely locomotive appendages of other crustaceans." Uniting these two classes together still under the name of ANNULOIDA, Professor HUXLEY now thinks it would be better, instead of retaining this as a division of the subkingdom ANNULOSA, to elevate it, in like manner, to the rank of a "distinct primary division of the animal kingdom."

---

* Med. Times, 1856, ii. p. 27.

† On the Elements of Comp. Anat. 1864, p. 75.

Let us now turn our attention more particularly to the class *Scolecida*: in this Professor HUXLEY includes (provisionally rather than with any feeling of certainty) seven groups, "the *Rotifera* (or wheel animalcules), the *Turbellaria**, the *Trematoda* (or flukes), the *Tæniada* (or tape-worms), the *Nematoidea* (or thread-worms), the *Acanthocephala*, and the *Gordiaceæ*" (p. 47). Of these, he seems pretty confident that the first four groups have such a relationship as to demand their union in a single class on the ground of a certain similarity in the arrangement of their nervous ganglia, and from the fact of their all possessing that peculiar apparatus of vessels opening externally, which has been called a "water-vascular system," whilst no heart, or vessels of any other kind are known to exist. He imagines also that the system of reticulating canals beneath the integument of the *Acanthocephala* must be a modification of this apparatus.

With regard to the Nematoids and their near allies the *Gordiaceæ* he is more doubtful, though he says, "If the system of canals, in some cases contractile, which open externally near the anterior part of the body (fig. 22), and were originally observed by Von SIEBOLD, and since by myself and others, are to be regarded as homologous with the water-vessels of the *Trematoda*, this question must, I think, be answered in the affirmative†. It is almost the only system of organs in the *Nematoidea* which gives us a definite zoological criterion, the condition of the nervous system in these animals being still, notwithstanding the many inquiries which have been made into the subject, a matter of great doubt."

Our increased knowledge concerning the various modifications of the contractile canals in the Nematoids, and the positive nature of our information relating to the nervous system of these animals, now place us in a much more favourable position for considering the affinities of this particular group, and also tend, as I have already pointed out‡, not only to throw considerable light upon the functions of the water-vascular system, but also to bind more intimately together the two classes *Scolecida* and *Echinodermata*.

---

* Including *Nemertidæ* and *Planariæ*.

† As to whether the Nematoids should be grouped with the four orders before mentioned.

‡ See p. 603.

It seems to me that in the present state of our knowledge we may be justified in looking upon the *Nematoidea*, and in all probability the *Gordiaceæ*, as close allies of the *Echinodermata*, leading to and connecting these with the *Scolecida* through their affinities to the *Acanthocephala.*

In the first place, the nervous system of the Nematoids is remarkably similar to that of the Echinoderms. In all adult specimens it is described by Professor HUXLEY as "a ring-like or polygonal ganglionated cord situated superficially to that part of the ambulacral system which surrounds the mouth, and sending prolongations parallel with and superficial to the radiating ambulacral trunks"[*]. And elsewhere[†] he states that "the circle round the mouth has rather the nature of a commissure than of a ganglionic centre." Scarcely anything can be more close than the correspondence of this description with the actual condition of things fully proved to exist in certain genera of Nematoids. This similarity is especially notable as regards the characters of the œsophageal ring: the agreement is here complete, and any difference as regards the arrangement of peripheral branches is nothing more than might be expected from the diversity in external form of the respective animals. If we take next the vascular system—accepting the views propounded by Professor HUXLEY as to the probable homological identity of the water-vascular system of the *Scolecida* with the ambulacral system of the *Echinodermata* —there can be little doubt that the so-called ventral glands in some, and the much more developed system of canals in other Nematoids, each having a similar communication with the exterior, can have their homologues only in these two systems, although their relationship is much more marked to the vessels of the Scolecids than to those of the Echinoderms. In both Nematoids and Scolecids the tubes immediately communicating with the exterior have been observed contracting and dilating in a kind of rhythmical manner, and the contents of each have been seen to consist of a clear fluid containing a larger or smaller quantity of suspended molecules. And the fact that as yet no cilia have been recognized in any part of this system of canals in the Nematoids—even though they are really absent, and their non-discovery has not been due merely to the intrinsic difficulties of the investigation—seems to be no real objection, since though such ciliated prolongations in connexion with the non-ciliated contractile tubes have been distinctly recognized in many *Trematoda* and *Tæniada*, still there are some of the former, such as *Distoma excisum* observed by HUXLEY, and *Distoma tereticolle*, *D. perlatum*, and *D. nodulosum*, together with *Amphistoma subclavatum*, according to AUBERT, in which "no cilia at all exist in any part of the water-vascular system, so that in these *Trematoda* its condition is, as it were, diametrically opposed to that which it exhibits in *Aspidogaster*"[‡]. The method of development of these tubes in the Nematoids according to all *à priori* possibility, and also from what I have seen in the young of *Dracunculus medinensis*, appears to be similar to that by which the water-vessels of the Scolecids and the ambulacral vessels of the Echinoderms originate; and for the reasons before stated[§], I think we have strong evidence for the belief that the excretory gland, opening externally in the œsophageal region of many Nematoids in which, so far as yet observed, the lateral vessels are wanting, is the rudimentary homologue of this system of canals, and may be considered as a permanent record of a transitory stage in their development in other species, as well as in that of the more complex form of this apparatus usually met with amongst the Echinoderms and Scolecids. An objection that may perhaps be urged to the homology of this apparatus in the Nematoids with that of the ambulacral system in the Echinoderms, is, that the latter system opens in the dorsal region of the body, whilst the former has its exit in the ventral. To this I would reply, that, as in the Echinoderms, this system opens in the Nematoid on the same aspect of the body as the genital organs and the rectum, and considering the bilateral symmetry of these latter animals together with the terminal position of their mouth, it is a matter of indifference for the purposes of transcendental anatomy which surface of the body is considered as dorsal and which as ventral: but seeing that these systems in the Echinoderms open undoubtedly upon the dorsal aspect of the body, and that the cloacal aperture of the same system is in a similar situation in the Rotifera (one of the groups of *Scolecida*), it seems pretty evident that in a developmental and homological point of view, that which has hitherto been spoken of as the ventral aspect of the Nematoids should be considered in reality as the dorsal. So far as the structure of the nervous system of the Nematoids is concerned, it also lends support to this view, since undoubtedly a much larger number of ganglion-cells are situated on what has hitherto been described as the ventral part of the œsophageal ring than can be met with in connexion with its opposite half. But the preponderance of ganglionic nervous matter in an œsophageal ring is usually *on* instead of beneath the œsophagus. The position of the ocelli in the free Nematoids is the only fact seeming to militate against this view; but I think this objection cannot be allowed much weight, seeing that the ocelli appear to be comparatively trivial organs which may be present or absent even in species of the same genus.

---

[*] Elements, p. 46.

[†] Med. Times, 1856, ii. p. 635.

[‡] Med. Times, 1856, ii. p. 133.

[§] See p. 597.

In the Echinoderms and in certain genera of free Nematoids there remain, however, certain other vessels which have not yet been accounted for. In the former animals I allude to that apparatus of vessels which is generally described as their "vascular system," and concerning which our knowledge is still somewhat defective. It is not absolutely proved that this is quite distinct from the ambulacral system, and our knowledge of the way in which it is developed is also obscure. Nothing more definite can at present be said of the simple lateral vessels existing amongst the free Nematoids in the genera *Tylenchus*, *Aphelenchus*, and *Plectus*, I could only ascertain that such vessels exist, and in *Tylenchus* at least, without the shadow of a doubt, that they float free from the integuments along either side of the abdominal cavity. Whether they communicate with one another, or with the exterior could not be ascertained, though, as before stated, there is slight evidence to show that in the genus *Plectus* these tubes do communicate with the exterior, each by means of a lateral, cervical, integumental pore*.

---

* See note, page 619.

In these lateral vessels, even when they were fairly exposed to view by being squeezed out from the cavity of the body of adult specimens of *Tylenchus tritici*, no granules or cilia could be detected; they appeared to me to contain a colourless fluid, though DAVAINE[*] described it as "légèrement rougeâtre," and also spoke of the lateral vessel itself as "susceptible de contractions et d'expansions alternatives et lentes."

The Echinoderms have long been remarkable for the number of pores of different kinds, opening either through their calcareous external skeleton, or through their coriaceous integument as existing in the *Holothuriadæ*; and from what I have made known in the earlier portion of this memoir concerning the prevalence, and in some species amazing number of integumental channels met with in the Nematoids, it becomes an interesting question to ascertain whether any resemblance, either as regards distribution or function, can be traced between these structures in the two groups of animals.

In the Echinoderms these pores are of three kinds; first and by far the most numerous are the so-called "ambulacral pores," mostly arranged in double series along the five pairs of ambulacral avenues radiating from the mouth and destined to give exit to the tubular feet in connexion with the ambulacral vessels. In some Echinoderms these are the only kind of pores existing, but in the *Asteriadæ* there are on the antambulacral surface other pores through which protrude small ciliated tubes imagined to have a respiratory function. In the Starfishes these are generally aggregated into groups[†]. Pores probably having a similar function are met with also in some Crinoids; "but it is in the Cystideans that this system of antambulacral pores attains its greatest development"[‡]. Still other pores, larger and definite in number, have been met with in the Echinoderms. Professor FORBES, speaking of *Cribella oculata*, one of the Asteriadæ, said:—"It received its name of *oculata*, either on account of the moniliform pores, or the five dark spots which occasionally mark the origin of the rays. The pores on the surface are not characteristic of this genus only, as Professor Agassiz seems to think. They may be seen in many other Starfishes, and in the young of almost all the species. In the living animal a brownish peritoneal membrane pouts out at each pore. Are they not subservient to respiration"[§]? He says, moreover (p. 152), that five similar pores are to be met with in most of the Sea-Urchins. Here we have, then, amongst the Echinoderms pores subservient to two distinct uses, the one locomotory in relation with the highly developed ambulacral system of vessels, and the other respiratory, whilst of these latter there are two varieties, those of the one set being small, numerous and indefinite in number, whilst those of the other are definite and much larger in size.

In the Nematoids two varieties of integumental pores are met with: one kind consisting of the two large, lateral, cervical pores, together with the two similar latero-ventral, caudal pores, which perhaps may be analogous to those last mentioned as existing in the Echinoderms; whilst the other variety includes an indefinite number of much smaller integumental channels, which, as far as function goes, are in all probability also respiratory and may be analogous to the second variety, or antambulacral pores in the Echinoderms, though in their modes of *distribution* they present many resemblances to the different modifications in the arrangement of the first or ambulacral series. Seeing that the apparatus in the Nematoids supposed to be homologous with the ambulacral vessels of the Echinoderms subserves an entirely different function, and that the locomotive feet are no longer required, we can well imagine that the pores developed in connexion with them in the Echinoderms would be unrepresented in the Nematoids. Either, then, the pores existing in the Nematoids may be considered as the homologues of the ambulacral pores, with which they exhibit so close a correspondence in the method of their distribution though subservient to a different function, or, these being absent altogether, we may suppose their vacant place and method of distribution (so characteristic of the Echinoderm type) to have been appropriated in the Nematoids by the representatives of the respiratory antambulacral pores of the Echinoderms. The arrangement of the ambulacral pores in the Echinoderms is generally along lines radiating from the mouth; and though five, or multiples of five, are the prevailing numbers met with amongst these animals, still in the family *Spatangaceæ* the ambulacral pores are distributed along four double lines instead of five, whilst in some *Holothuriæ* they are confined to one aspect of the body, and in others are scattered irregularly over its whole surface. So amongst the Nematoids the integumental pores may be found in some genera, such as *Oncholaimus* and *Leptosomatum*, along four longitudinal lines radiating from the mouth; in *Dorylaimus* and others along two; in *Trichosoma** along one, two, or three; in *Trichocephalus* along one widening band, and in such numbers as infinitely to exceed the 3720 ambulacral pores calculated by Professor FORBES to exist in the Common Egg-urchin; whilst in EBERTH'S *Enoplus cæruleus*† they would appear to be more sparingly scattered over the whole surface of the body.

---

[*] Recherches sur l'Anguillule du blé niellé, 1857, p. 26.

[†] SHARPEY, art. Cilia, vol. i. p. 615, and art. Echinodermata, vol. ii. p. 40. Cycl. of Anat. and Phys.

[‡] HUXLEY, Med. Times, 1856, ii. p. 657.

[§] Hist. of Brit. Starfishes, 1841, p. 101.

Surely there must be some homologies between these organs existing in the Echinodermata and Nematoidea respectively. And if not, where else are we to look amongst the lower invertebrata for the representatives of these integumental pores which have been shown to be so numerous in the free and in some of the parasitic Nematoids?

All the Nematoids and almost all the Echinoderms are diœcious; and though in the majority of the latter the orifices of the genital organs are multiple, still in the *Holothuriadæ* there is only a single exit in the dorsal region of the body. As pointed out by MÜLLER, the Echinoderms never exhibit a perfect radial symmetry, and in some whole families even, such as the Spatangoids and Clypeastroids, there is an approximation to a bilateral symmetry; whilst the fact is as certain as it is remarkable, that "in the larval state * * radial symmetry is totally absent, the young Echinoderm exhibiting as complete a bilateral symmetry as annelids or insects"‡. The peculiar method by which

---

* EBERTH, Untersuch. über Nemat. Taf. vi. u. vii.

† *Loc. cit.* Taf. vii. 7.

‡ HUXLEY, Elements, p. 47.

the adult Echinoderm is produced from and out of this ciliated larva, affords a process of development certainly varying as much as possible from the simple and direct evolution of the young animal from the yelk-mass, such as obtains amongst the Nematoids both free and parasitic; but such differences in the method of development of apparently nearly allied animals may be paralleled by the discrepancies in this respect existing between the simple *Hydræ* and the various families of the *Compound Hydroida*, and also between the different families of Annelida. Concerning these latter Dr. CARPENTER remarks*, "In the history of the development of the several orders of the Annelida there exists a very marked diversity; for whilst the young of the *Terricolæ* and *Suctoria* do not usually issue from the egg until they have acquired the characteristic forms of the parent (although the number of segments may be subsequently augmented), the embryos of the *Dorsibranchiata* and *Tubicolæ* come forth in a state of far less advancement, and only acquire their perfect form by such a series of changes as deserves the designation of a metamorphosis."

It remains to be pointed out, as before alluded to, that although the quinary arrangement of organs and parts is so prevalent amongst the Echinoderms, it is far from being invariable; for, as remarked by Professor FORBES, "monstrous starfishes and urchins often appear quadrate and have their parts fourfold, assuming the reigning number of the Actinodermata," or Polypes. In the Nematoids, too, we meet with a quadrate mixed with a ternate type of formation. The lateral and median lines radiate crucially from the mouth and extend along the body, alternating with four great longitudinal muscles; but whilst we have here a radiate arrangement, which may also be considered bilateral, this approach to a bilateral symmetry is disturbed by the fact that the œsophageal canal in the Nematoids is almost invariably triquetrous, that the number of teeth in the pharyngeal cavity of the free Nematoids, when such exist, is generally three, and that the same number applies to the cephalic lobes of the *Ascarides*, and a multiple of it to those of the *Spiropteræ*. As another notable instance of deviation from a bilateral symmetry, may be cited the remarkably unsymmetrical distribution of the peculiar transverse pairs of vessels existing in some members of the genus *Ascaris*†.

By reason of these various resemblances, though more especially on account of the remarkable identity in the structure and arrangement of their nervous systems, I think it most in accordance with the nature of ascertained facts to look upon the Nematoids as close allies of the *Echinodermata*—more closely allied to them, in fact, than to the *Scolecida*. Whilst, however, it would be difficult to assign to the order *Nematoidea* a zoological position in either of these classes, there can be little doubt that their organization—uniting as it does, in a remarkable manner, some of the chief characteristics of both classes—presents an intermediate bond of union strengthening the alliance between them, and making the division ANNULOIDA a more coherent assemblage than it formerly appeared[*]. It seems to me, moreover, that the Nematoids approach the Scolecids principally through their affinities to the order *Acanthocephala*. For after a comparison of the various descriptions given of the anatomy of the *Acanthocephalæ*, their deep integumental layer with its four cord-like developments, its system of vessels, and communicating lemnisci, seem to me to find almost an exact parallel in the corresponding structures of the Nematoids; whilst their nervous system, instead of exhibiting the ring-like form met with in the Nematoids, consists of a single ganglion from which peripheral branches are sent off, thus conforming pretty closely with what must be considered as the typical form of this system in the class *Scolecida*. And, again, whilst the *Acanthocephalæ* agree with the Nematoids in being diœcious, they approximate to the *Tæniadæ* by the absence in both of all vestiges of the organs of digestion.

---

* Princip. of Comp. Physiol. 1854, p. 593.

† MÜLLER'S Archiv. According to the descriptions given by MEISSNER, the departure from the bilateral and prevalence of a ternary arrangement must be still more striking amongst the *Gordiaceæ*, since he describes in these animals three great longitudinal muscles instead of four, alternating with three cellular bands apparently homologous with the lateral bands of the Nematoids.

All attempts hitherto to subdivide the order *Nematoidea* into families and subfamilies have been more or less unsatisfactory, and at present our knowledge concerning the anatomy of the representatives of so many genera is in such a defective condition, that it would be quite useless to attempt to produce anything more satisfactory. As a provisional classification, I think that of DUJARDIN is the best; and I further desire it to be understood that I look upon the present location of the free Nematoids in a distinct family as a mere temporary arrangement, which will ultimately have to give place to a more philosophical rearrangement of all the genera composing the order. Any such classification of the genera must, I think, be based principally upon the presence or absence of the ventral excretory system, its various modifications in those genera in which it is found, and the arrangement of the integumental pores where it is absent. As characters of secondary and tertiary importance, I should regard the arrangement of the organs of generation, and the variations in the nature of the pharynx and œsophagus.

EXPLANATION OF THE PLATES[†].

PARASITIC NEMATOIDS.

PLATE XXII.

Fig. 1. Anterior extremity of a *Dispharagus* from the gizzard of *Colymbus septentrionalis*, dorsal aspect:—*a*, *a*, lateral head-lobes; *b*, elongated pharynx; *c*, œsophagus; *d*, œsophageal ring of doubtful nature; *e*, *e*, lateral integumental processes.

Fig. 2. Posterior extremity of same, ventral aspect:—*a*, *a*, lateral caudal pores; *b*, *b*, lateral bands in profile.

---

[*] If, as seems probable, further investigations should make it desirable to place the orders *Nematoidea* and *Gordiacea* apart, in a distinct class, I would propose for this the name PSEUDHELMINTHIA as a suitable designation.

[†] Through a mistake on the part of the artist, only discovered when it was too late to be altered, the arrangement of the figures in these Plates is quite different from what I had intended. Some of the defects will be pointed out in footnotes, so as to rectify the faulty arrangement as much as possible.

Fig. 3. Anterior extremity of same, lateral aspect:—letters *a–e* same as in figure 1; *f*, mid-ventral pore; *g*, rudimentary gland in connexion with same.

Fig. 4. Anterior extremity of a half-grown specimen of *Ascaris spiculigera*, showing lateral cervical pores (*a*, *a*,) and one of smaller intermediate head-lobes.

Fig. 5. Ventral aspect of posterior extremity of same specimen:—*a*, *a*, lateral caudal pores opening into well-marked surface depressions; *b*, anal cleft; *c*, *c*, lateral bands.

Fig. 6. Anterior extremity of *Ascaris piscium*, from the Haddock:—*a*, *a*, two of the four head papillæ; *b*, left lateral band; *c*, its axial unbranched vessel, which opens externally at *d*.

Fig. 7. External aspect of lateral band and its contained vessel, more highly magnified: —*a*, *a*, large, highly refractive particles in the band itself; *b*, undulating axial vessel, with an appearance of imperfect septa or bridles at intervals.

Fig. 8. Transverse section of same species, showing vessel in left lateral band only, and thick glandular walled intestine (*a*) as in Plate XXVI. fig. 10.

Fig. 9. Contiguous portions of œsophagus and intestinal canal of same species, showing an œsophageal cæcum directed posteriorly (*a*), and an intestinal cæcum anteriorly (*b*).

Fig. 10. Lateral aspect of anterior extremity of *Heterakis vesicularis*:—*a*, mid-ventral pore communicating with a wide tube; *b*, much narrower lateral band.

Fig. 11. Anterior extremity of *Heterakis acuminata*:—showing (*a*) a large transverse mid-ventral aperture in communication with the dilated extremity of an excretory tube.

Fig. 12. Portion of integument of same, more highly magnified, showing two of lateral pores.

Fig. 13. Posterior extremity of male of same species:—*a*, single slipper-shaped spicule; *b*, *b*, well-marked ventral suckers; *c*, *c*, integumental channels; *d*, *d*, pale internal bands, probably muscular; *e*, seminal tube; *f*, intestine.

Fig. 14. *Ascaris lumbricoides*, dorsal aspect of anterior extremity:—*a*, *a*, anterior latero-cervical pores; *b*, *b*, suctorial papillæ of dorsal head-lobe; *c*, *c*, large pores on latero-ventral head-lobes; *e*, *e*, *e*′, fine channels through the anterior borders of the head-lobes; *f*, *f*, lateral bands in relation with the cervical pores.

Fig. 15. Ventral view of the posterior extremity of the same:—*a*, anal cleft; *b*, *b*, latero-ventral caudal pores; *c*, *c*, lateral bands.

Fig. 16. One of cervical integumental channels, more highly magnified.

Fig. 17. Side view of a portion of dorsal head-lobe:—*a*, chitinous portion of integument; *b*, one of suctorial papillæ; *c*, deep cellulo-granular layer of integument.

Fig. 18. Side view of a portion of one of latero-ventral head-lobes:—*a* and *c*, same as in last figure; *d*, large pore; *e*, one of anterior, fine integumental channels.

Fig. 19. Anterior extremity of same, lateral aspect:—*g*, ventral pore; *h*, sheath of exit-tube of lateral vessels. Other references same as in fig. 14.

Fig. 20. Posterior extremity of male of same species, lateral aspect, showing the series of suctorial papillæ of one side of body (*a*, *a*, *a*, *a*); *b*, one of posterior latero-ventral pores; *c*, larger of two spicules, protruded.

Fig. 21. Magnified view of surface of integument, corresponding to one of these ventral papillæ:—*a*, central aperture leading to apex of papilla; *b*, slightly concave depression in which it is situated; *c*, linear markings of integument.

Fig. 22. One of bladder-like developments from muscle-cell of *Ascaris lumbricoides*, highly magnified*.

Fig. 23. Anterior portion of body of *Ascaris megalocephala* slit open in the dorsal line, the head-lobes cut off and œsophagus removed:—*a*, *a*, lateral bands; *b*, dorsal median line; *c*, ventral median line; *d*, position of œsophageal band of nervous system; *e*, arch of excretory vessels; *f*, mid-ventral orifice.

PLATE XXIII.

Fig. 1. Transverse section of the integument of *Ascaris lumbricoides* posterior to the termination of œsophagus:—*a*, chitinous portion of integument; *b*, deep cellulo-granular layer; *c*, *c*, median lines; *d*, *d*, lateral bands; *e*, *e*, axial vessels or ducts.

Fig. 2. Transverse section of the entire animal, slightly anterior in position to that of last figure:—letters from *a*—*e* same as in last figure; *f*, *f*, *f*, *f*, sections of the four great longitudinal muscular bands; *g*, *g*, *g*, *g*, the four sets of transverse muscular fibres, proceeding from the muscle-cells to the median lines; *h*, *h*, bladder-like developments from the muscle-cells; *i*, transverse section of intestine.

Fig. 3. Transverse section of the male about 1¼ inch from its posterior extremity. Letters *a*–*i* same as in last figure. The lateral bands are here seen above the median horizontal plane of the body, and arising from them are strong muscular processes, latero-ventral (*k*, *k*), chiefly proceeding to the muscles on either side of the mid-ventral line; *l*, *l*, latero-ventral papillæ at their greatest distance from one another; *m*, male genital tube. The axial canal of the lateral band cannot be recognized in transverse sections of this region

Fig. 4. Transverse section of the male a short distance above the ano-genital cleft. Letters of reference as in fig. 3, with the addition of *n*, *n*, for the two unequal-sized male spicules, and *o*, *o*, the sheaths in which they are contained. The most notable points in this section are the deviation from the cylindrical form, the almost dorsal position of the lateral bands, the strength and bulk of the latero-ventral muscles, and the absence of the ordinary transverse processes, together with the extreme thickening of the walls of the genital tube,

and the compression of the alimentary canal with complete obliteration of its cavity.

---

* This figure ought to have followed fig. 9 of the next Plate, and fig. 23 of this Plate should have formed a part of Plate XXV.

Fig. 5. Transverse section of one of lateral bands, with neighbouring muscle-cells and integument of *Ascaris lumbricoides* $\frac{3}{4}''$ from the anterior extremity:—*a*, external chitinous layer with transverse markings; *b*, thick homogeneous layer devoid of marking; *c* and *d*, layers with oblique markings in opposite directions; *e*, internal chitinous layer with very delicate longitudinal markings; *f*, cellulo-granular layer of integument; *g*, loose fibrous membrane forming internal boundary of this; *h*, one of nucleated cells found in this layer; *i*, fibrous framework met with in the anterior portion of lateral bands; *k*, transverse section of axial duct or vessel; *l*, contractile tissue of muscle-cell; *m*, contained granular medullary substance; *n*, section through the central part of a small muscle-cell, showing the mode of origin of the bladder-like appendages.

Fig. 6. A portion of one of the lateral ducts removed from the lateral band:—*a*, its lumen; *b*, *b*, adhering nucleated cells of the lateral band.

Fig. 7. A portion of the integument seen from the inner surface, the body of the animal having been slit open and the muscles removed:—*a*, right lateral band; *b*, its axial duct; *c*, *c*, median lines; *d* and *e*, a pair of delicate vessels runrunning through the cellulo-granular layer of integument from median line to median line, and crossing one another in the substance of lateral band.

Fig. 8. One of muscle-cells, lateral aspect:—*a*, contractile portion; *b*, bladder-like development; *c*, transverse muscular prolongations; *d*, nucleus of muscle-cell; *e*, superficial granular material, sometimes containing delicate cells.

Fig. 9. A more elongated muscle-cell, with no bladder-like development seen, but a stronger transverse prolongation.

Fig. 10. Showing the constitution of intestinal wall:—*a*, external structureless membrane; *b*, *b*, two columnar hepatic cells; *c*, very thin internal structureless layer, perhaps formed by a thickening of the cell-wall at this part.

Fig. 11. Tessellated appearance presented by extremities of hepatic cells.

Fig. 12. Floating cells from the general cavity of body of *Ascaris lumbricoides*.

Fig. 13. External transverse markings of the integument of same.

Fig. 14. Portions of the two sets of lamellæ with oblique markings.

Fig. 15. Internal chitinous layer with very fine longitudinal markings.

Fig. 16. Section through anterior part of one of lateral bands and adjacent integument of *Ascaris megalocephala*; references same as in fig. 5. The principal differences are that the band is here absolutely smaller, and the vessel absolutely larger; whilst no fibrous framework exists in the band, whose complete continuity with the deep integumental layer may be well seen.

PLATE XXIV.

Internal aspect of anterior extremity of *Ascaris lumbricoides*, slit open in the mid-dorsal line (œsophagus removed, muscles not represented, lateral bands only in outline). Showing nervous system and so-called "vascular arch," outlined with the camera lucida:—*a*, œsophageal band; *b*, median group of ganglion-cells; *c*, *c*, two submedian ventral groups, the cells of which are mostly bipolar, connected with those of last group and with others, *d*, *d*, imbedded in the substance of the lateral bands; *e*, a large peripheral fibre which was seen to pass in the cellulo-granular layer beneath the muscular bundles; *f*, *f*, nervi submediani; *g*, *g*, nervi laterales; *h*, *h*, very large ganglion(?)-cells; *i*, *i*, bundles of fibres, going to the dorsal head-lobe, chiefly in connexion with the lateral ganglion-cells; *k*, *k*, two distinct bipolar cells on each side; *l*, *l*, lateral ventral head-lobes; *m*, *m*, two halves of dorsal head-lobe; *n*, *n*, lateral bands; *n'*, ventral median line; *o*, "vascular arch"; *p*, large granular cell in substance of wall of vessel on left side; *q*, ventral pore, situated in a plane external to the arch itself, with which it is connected by a single outgoing tube.

PLATE XXV.

Fig. 1. Section through the middle of head-lobes and triangular pharynx of *Ascaris megalocephala*.

Fig. 2. Section of body of same immediately behind the head-lobes:—*a*, chitinous portion of integument; *b*, cellulo-granular layer of same; *c*, *c*, *c*, commencement of longitudinal muscles; *d*, large œsophagus, showing a trilobate form, with thick walls, composed of transverse, radiating fibres, and large, triradiate lumen.

Fig. 3. Section of same slightly anterior to position of nervous ring, showing a blending of prolongations from lateral and median lines around the œsophagus, in which are imbedded the anterior peripheral nerves; letters *a*–*d* same as in last figure; *e*, *e*, lateral bands; *f*, *f*, median lines.

Fig. 4. Section of same (female) just posterior to termination of œsophagus, and anterior to the situation of genital organs; parts similar to those described in Plate XXIII. fig. 2, the most noticeable differences being the smaller size of the lateral band and the greater distinctness of its contained tube, and the alteration in form of the developments from muscle-cells (*h*, *h*)*.

Fig. 5. Section of female of same species through the rectum, slightly anterior to the anal cleft:—*a*, structureless wall of intestine devoid of its cellular lining; *b*, contractile tissue in connexion with the lateral bands, surrounding the intestine like a sphincter, and having imbedded in its substance (*c*, *c*, *c*) one upper, large, and two lower, smaller, densely granular cells, similar to that met with on the left side of vascular arch; *f*, *f*, median lines.

---

* See also Plate XXIII. fig. 16.

Fig. 6. Section of same through latero-ventral caudal pores:—*a*, chitinous portion of integument; *b*, deep cellulo-glandular portion forming a pretty thick uniform layer; *c*, *c*, caudal pores.

Fig. 7. Section of male *Ascaris megalocephala* a short distance above ano-genital cleft; references same as in Plate XXIII. fig. 4. Principal differences to be noted are the presence of two *equal* male spicules in strong sheaths, the greater thickness of the longitudinal muscle-bands, and the double row of ventral papillæ on each side.

Fig. 8. A large tripolar ganglion-cell seen in substance of left lateral band, anterior to œsophageal ring.

Fig. 9. Exit-tube and arch of excretory vessels with the large granular cell in a thickening of the walls of the left branch; the lumen in this situation is also narrowed, and is often somewhat variable in size in other parts of the vessels.

Fig. 10. Diagrammatic representation of the arrangement and distribution of the transverse vessels contained in the deep cellular layer of a medium-sized *Ascaris megalocephala*, the body having been slit up in the mid-dorsal region, and the viscera with great longitudinal muscles removed:—*a*, right, and *a'*, left lateral band; *b*, ventral median line; *c*, ventral excretory pore; *d*, vulva; *e*, anal cleft.

Fig. 11. Portion of integument of same more highly magnified, showing a pair of transverse vessels, which do not cross one another:—*a*, right lateral band; *b*, its contained vessel; *c*, *c*, median lines; *d*, *d*, thickenings of deep portion of integument on either side of lateral band; *e*, *e*, transverse vessels, which magnified to this extent, appear to be simple lacunar channels running through the substance of cellulo-granular layer in an undulating manner.

Fig. 12. Portion of one of these vessels isolated, and more highly magnified; its walls showing longitudinal fibres and a few intermixed granules.

Fig. 13. Section of muscle-cells and integument of *Ascaris megalocephala*:—*a*, chitinous portion of integument; *b*, cellulo-granular layer; *c*, fibrous aponeurosis bounding same; *d*, contractile portion of muscle-cell; *d'*, contained medullary granular matter; e^1–e^6, sections through different portions of muscle-cells, from narrow closed extremities to wide median portions, from which the transverse prolongations (*f*, *f*) are given off.

*Fig. 14. Transverse section of *Dracunculus medinensis*:—*a*, chitinous portion of integument; *b*, deep cellulo-granular layer not presenting the usual lateral bands, though the muscular interspaces are unusually wide; *c*, bounding wall of greatly developed uterine sac; *d*, compressed intestine; *e*, *e*, space occupied by dorsal muscles; *e'*, *e'*, ditto by ventral.

*Fig. 15. Glandular portion of one of muscle-cells of same separated and highly magnified, showing its internal loculated structure and central nucleus.

---

* These two figures should have formed part of Plate XXVII., with the others (figs. 20–24) illustrative of the anatomy of *Dracunculus medinensis*.

PLATE XXVI.

Fig. 1. Transverse section of the anterior extremity of *Ascaris marginata* through its œsophageal (nervous) ring:—*a*, *a*, lines seen in chitinous portion of integument; *b*, *b*, *b*, *b*, the four principal communications of muscles with sheath of œsophageal ring; *c*, *c*, ganglion-cells in substance of ring.

Fig. 2. Section of same slightly posterior to arch of excretory vessels:—*a*, *a*, unequal-sized lateral bands; *b*, *b*, unequal-sized axial vessels; *c*, œsophagus; *d*, anterior intestinal cæcum; *e*, *e*, space occupied by dorsal muscles; *f*, *f*, ditto by ventral.

Fig. 3. Section of three muscle-cells of same species.

Fig. 4. Transverse section of anterior extremity of *Ascaris mystax*, slightly posterior to arch of excretory vessels:—*a*, *a*, lateral integumental alæ; *b*, œsophagus; *c*, *c*, space occupied by dorsal muscles; *d*, *d*, ditto, by ventral; *e*, *e*, narrow projections of chitinous layer into substance of lateral bands; *f*, *f*, axial vessels.

Fig. 5. Transverse section of intestinal canal of the same:—*a*, thick internal structureless cuticle; *b*, columnar hepatic cells; *d*, thin external structureless membrane.

Fig. 6. Anterior half of body of *Ascaris osculata*, slit up in dorsal region (× 3), showing position and nature of so-called "lemniscus," developed from left lateral band (*a*) and the course of the main excretory canal (*b*) which communicates with the exterior at *c*:—*d*, right lateral band.

Fig. 7. Portion of the lemniscus from the situation indicated by *e* in last figure, more highly magnified:—*a*, portion of the main excretory vessel, from which are given off innumerable, inosculating, thin-walled branches, in the middle of the delicate cellulo-granular material of which this development is composed.

Fig. 8. Showing the narrow termination of the lemniscus (*a*) on the side of the bilobed lateral band (*b*), and also the gradual termination of the main excretory vessel (*c*).

Fig. 9. Transverse section of anterior extremity of *Ascaris osculata*, through the lateral cervical pores (*a*, *a*), showing the very unequal size in this region of the two bilobed lateral bands (*b*, *b*), and the single vessel (*c*), just as it is about to leave the large lower lobe of the left band in order to reach the mid-ventral pore. The intestinal cæcum does not reach so far forward as the situation of this section.

Fig. 10. Transverse section of the body of *Ascaris osculata*, slightly posterior to termination of œsophagus:—*a*, intestinal canal with extremely thick glandular walls; *b*, *b*, bilobed lateral bands, nearly equal in size; *c*, lemniscus projecting from the lower lobe of left band across the ventral region of the body, its free extremity being connected by some delicate fibro-cellular tissue with the

lower lobe of right band; *d*, main vessel from which branches indicated by dark lines are given off; *e*, central cavity of lemniscus; *f*, *f*, space occupied by dorsal muscles; *f'*, *f'*, ditto by ventral; *g*, cellulo-granular layer of integument, having no developments in mid-dorsal and ventral region; *h*, chitinous portion of integument.

Fig. 11. Transverse section of anterior extremity of same, in the situation of its central nervous system. Parts same as in fig. 1, except *a*, which here represents the anterior excretory duct slightly posterior to its point of communication with the exterior, near the bases of the two ventral head-lobes.

Fig. 12. Transverse section of the posterior extremity of the male of same species, just above ano-genital cleft. References same as in Plate XXIII. fig. 4, and Plate XXV. fig. 7. The most notable points are the extreme size of the latero-ventral muscular bands (*k*, *k*), and the entire obliteration of the lateral lines. The two dorsal muscles appear as one band only, equalling in size each one of the widely separated ventral muscles, which are now more lateral in position.

Fig. 13. Transverse section through œsophageal region of *Ascaris spiculigera*:—*a*, *a*, lateral bands, each having a horizontal fibrous septum; *b*, anterior portion of lemniscus, with its axial vessel and radiating branches; *c*, œsophagus; *d*, anterior intestinal cæcum; *e*, coagulated material, containing small cells or granules, in general cavity of body.

Fig. 14. Transverse section of same near the middle of lemniscus, showing its connexion with the lateral bands, as in fig. 10. In this species the lemniscus is thicker, contains only a very small central cavity, and the main excretory vessel occupies its axis, giving off inosculating branches on all sides.

Fig. 15. Section of same, nearly opposite the posterior termination of lemniscus:—*a*, the very thick chitinous portion of the integument; *b*, lemniscus near its termination, still showing axial vessel.

Fig. 16. Middle portion of lemniscus of *Ascaris spiculigera*, showing its small, broadly fiddle-shaped central cavity, and deviation of central vessel from its axial position.

Fig. 17. External layer of integument of same.

Fig. 18. Integument of same, more deeply focused.

Fig. 19. Section through the middle of the body of a female *Spiroptera obtusa*, showing the extreme inequality in the size of lateral bands (*a*, *a*):—*b*, *b*, median lines; *c*, intestinal canal; *d*, *d*, two ovarian tubes.

Fig. 20. Section close to anterior extremity of same, showing a ventral communication between the lateral bands, though no axial vessel could be detected.

Fig. 21. Section of muscle-cells and integument of same species:—*a*, thick chitinous portion of integument; *b*, very thin cellulo-granular layer; *c*, contractile portion of muscle-cell; *d*, medullary and bladder-like portion.

Fig. 22. Transverse section of a female specimen of *Filaria*, from the subcutaneous tissue of a water-bird:—*a*, *a*, rather broad, flattened lateral bands, in which no vessels could be detected; *b*, intestine; *c*, *c*, *c*, three oviducts filled with ova; *d*, three narrower extremities of same ovarian tubes.

PLATE XXVII.

Fig. 1. Anterior extremity of *Prothecosacter inflexus*, dorsal aspect:—*a*, œsophagus; *b*, *b*, lateral cervical pores; *c*, *c*, lateral bands.

Fig. 2. Posterior extremity of female specimen of same, ventral aspect:—*a*, *a*, latero-ventral caudal pores; *b*, *b*, terminations of lateral bands.

Fig. 3. Anterior extremity of same, lateral aspect:—*a*, triangular mouth in centre of somewhat flattened circular space; *b*, mid-ventral pore with an infundibuliform opening; *c*, right lateral band; *d*, process given off from same to ventral pore, in which, however, no vessel could be detected.

Fig. 4. Transverse section of same slightly posterior to the termination of œsophagus:—*a*, *a*, lateral band; *b*, *b*, almost imperceptible median lines; *b'*, *b'*, *b'*, *b'*, equally indistinct accessory longitudinal lines; *c*, *c*, intestinal canal held in position by fibrous processes; *e*, *e*, surface projections of integument corresponding with superficial markings.

Fig. 5. Transverse section of muscle-cells and integument of same, showing:—*a*, thick homogeneous chitinous portion of integument; *b*, very thin cellulo-granular layer of same; *c*, deep and very narrow muscular elements.

Fig. 6. Highly refractive particles filling the anterior part of general cavity of body of some specimens.

Fig. 7. Portion of integument, showing nature of its surface-markings due to ridges or minute elevations.

Fig. 8. Lateral aspect of anterior extremity of *Strongylus filaria*, with the two ventral glands (*a*) dissected out, and showing the manner in which they are connected with the single median pore.

Fig. 9. Posterior extremity of same:—*a*, lateral band; *b*, *b*, caudal pores here upper and lower instead of lateral; *c*, anal cleft.

Fig. 10. Portion of integument of a red-coloured *Strongylus* from the stomach of a Hare, showing its longitudinal and transverse markings.

Fig. 11. Anterior extremity of *Cucullanus heterochrous* (*Dacnitis esuriens*, Duj.), lateral aspect:—*a*, mid-ventral pore; *b*, sac in connexion with same; *c*, *d*, anterior and posterior branches on left side in connexion with sac, in which are seen molecules suspended in a clear fluid; anterior branch terminating cæcally opposite pharynx (*e*); *f*, œsophagus; *g*, intestine; *h*, fibrous band (probably nervous) surrounding œsophagus in this situation.

Fig. 12. Posterior extremity of same:—*a*, cæcal termination of posterior branch; *b*, left lateral caudal pore; *c*, anal cleft.

Fig. 13. Transverse section through body of same species in œsophageal region:—*a*, *a*, lateral bands; *b*, *b*, large axial vessels; *c*, œsophagus; *d*, *d*, thickenings of lining membrane forming longitudinal bands; *e*, *e*, muscle-cells.

Fig. 14. Lateral aspect of portion of *Trichosoma longicolle*:—*a*, *a*, segmented œsophagus; *b*, small lumen of same; *c*, one of œsophageal appendages; *d*, intestine; *e*, *e*, ova, within oviduct; *f*, *f*, integumental pores over situation of mid-ventral cellular band (*g*); *h*, mid-dorsal band.

Fig. 15. Magnified representation of integument in the situation of the peculiar dorsal band of *Trichocephalus dispar*.

Fig. 16. Portion of same near its termination, showing the integumental channels under different aspects—on the right-hand side they are seen as when looked down upon in the direction of their length, and on the left hand in intermediate positions between this and a direction at right angles to it.

Fig. 17. Portion of integument over and adjoining dorsal band of *Trichocephalus affinis*, showing, as in fig. 15, the cessation of transverse markings at border of band.

Fig. 18. Transverse section of same through anterior part of œsophageal region of body, showing the broad dorsal band consisting of integumental channels in connexion with a subjacent loculated cellular structure; no muscles covering this band internally, and nearly the whole of cavity of body occupied by the œsophagus, with narrow central lumen and thick cellular parietes.

Fig. 19. Portion of posterior part of œsophagus of same.

Fig. 20. Caudal extremity of adult *Dracunculus medinensis*:—*a*, anus; *b*, intestine; *c*, right lateral caudal pore*.

Fig. 21. Portion of integument with one of caudal pores, more highly magnified.

Fig. 22. Posterior extremity of young Guineaworm:—*a*, anus; *b*, intestine; *c*, right lateral caudal pore; *d*, outline of internal sac in connexion with same.

Fig. 23. Dorsal aspect of lateral caudal pores of same, with their attached sacculi.

Fig. 24. Lateral aspect of anterior extremity of young Guineaworm, showing (*a*) a rudimentary mid-ventral pore.

FREE NEMATOIDS.

PLATE XXVIII.

Fig. 1. Female *Dorylaimus stagnalis*.

Fig. 2. Male of same species.

Fig. 3. Anterior extremity of same species more highly magnified, ventral aspect:—*a*, *a*, deciduous portion of spear; *b*, central framework through which it

moves; *c*, permanent rigid shaft of spear; *d*, permanent spear itself lodged in substance of wall of œsophagus; *e*, *e*, two longitudinal contractile bands destined to move anterior portion of œsophagus and protrude spear; *f*, *f*, retinacula, binding these bands to parietal muscles; *h*, *h*, integumental pores.

---

* In Plate XXV. figs. 14 & 15, other points in the anatomy of this animal are illustrated.

Fig. 4. Portion of posterior extremity of same opposite the region where intestinal canal becomes narrowed (*a*):—*b*, *b*, thick chitinous portion of integument; *c*, *c*, lateral integumental channels through same; *d*, *d*, lateral bands seen in outline.

Fig. 5. Portion of œsophagus of same:—*a*, lumen; *b*, *b*, hyaline cells from œsophageal walls.

Fig. 6. Four of hepatic cells from walls of intestine of same, showing granular contents only, in the form of dark-coloured, highly-refractive particles.

Fig. 7. Group of glandular cells from surface of muscles of same.

Fig. 8. Three spermatic cells of same as they are most frequently seen.

Fig. 9. Later stage of same, more rarely met with, in form of elongated spindle-shaped filaments.

Fig. 10. Two hepatic cells of *Dorylaimus muscorum*, showing in each a homogeneous, central, nuclear body in addition to light-coloured particles.

Fig. 11. Terminal portion of œsophagus of *Rhabditis marina*, showing simple valvular apparatus closed.

Fig. 12. Same, valvular apparatus open.

Fig. 13. Motory spermatozoa of same species.

Fig. 14. Anterior extremity of *Plectus parietinus* highly magnified, ventral aspect:—*a*, *a*, lateral, circular, integumental spaces, probably having minute central apertures in communication with transparent flexuous vessels (*b*, *b*) by means of narrower and more rigid portions (*b*′, *b*′); *c*, mid-ventral pore in connexion with *d*, the curved, twisted and somewhat rigid duct in connexion with gland.

Fig. 15. One uterine segment and ovarian tube of same species:—*a*, vulva; *b*, uterus filled with large spermatic (?) cells; *c*, *c*, short thick ovarian tube containing unimpregnated ova.

Fig. 16. Bodies almost exactly resembling the spermatic corpuscles of fig. 27, though smaller, which were found filling the whole cavity of the body of a specimen of *Plectus cirrhatus*.

Fig. 17. Anterior extremity of adult *Tylenchus* (*Vibrio*) *tritici*, lateral aspect:—*a*, mid-ventral pore, communicating with curved rigid duct (*b*); *c*, one of lateral flexuous vessels; *d*, pharyngeal spear; *e*, mid-œsophageal muscular swelling.

Fig. 18. Spermatozoa of same species in different stages of development.

Fig. 19. Hyaline cells, such as completely fill all otherwise unoccupied parts of the cavity of the body of same species.

Fig. 20. Ventral gland of *Tylenchus Davainii*:—*a*, its distinct rigid duct; *b*, very indistinct terminal dilated portion.

Fig. 21. Minute granular cells, which were found distending the cavity of the body in a specimen of same species. See fig. 16 also.

Fig. 22. Minute almost granular spermatozoa of *Theristus acer.*

Fig. 23. Spermatozoa of *Comesoma vulgaris.*

Fig. 24. Large ovoid spermatic cells of *Monhystera vulgaris.*

Fig. 25. Small ovoid spermatozoa of *Enoplus communis.*

Fig. 26. Motory spermatic filaments of *Monhystera disjuncta.*

Fig. 27. Spermatozoa of an undescribed marine species.

Fig. 28. Portion of intestine of *Aphelenchus parietinus*, showing the indistinct granular aspect of its cellular layer, with a very distinct internal bounding membrane.

Fig. 29. A group of hepatic cells from intestine of *Oncholaimus attenuatus*, showing the very large size of homogeneous central nuclear bodies, the granules forming a lining superficial to these.

Fig. 30. Floating gland-cells from general cavity of body of same.

Fig. 31. Much larger cells with central nucleus from general cavity of body of *Leptosomatum figuratum.*

Fig. 32. Glandular layer and processes from surface of longitudinal muscles of *Symplocostoma longicolle*:—*a*, mass lying on surface of muscle (*b*); *c*, *c*, *c*, pedunculated growths from same, each containing in addition to finely granular matter, a central homogeneous body or nucleus ("vacuole"); *d*, secondary growth of same kind connected by very narrow peduncle with primary; *e*, one of these bodies with its pedicle torn seen floating freely in cavity of body.

Fig. 33. Anterior extremity of *Leptosomatum figuratum*, showing:—*a*, *a*, ocelli on dorsal aspect of œsophagus, each containing a rounded lens, imbedded anteriorly; *b*, œsophageal ring of uncertain nature; *c*, *c*, integumental pores in connexion with the lateral bands (*d*, *d*).

Fig. 34. Portion of lateral band of same species showing a distinctly cellular structure.

Fig. 35. Simple granular appearance of lateral band *Linhomœus hirsutus.*

Fig. 36. Anterior extremity of *Cyatholaimus ornatus*, lateral aspect:—*a*, tubular ventral gland; *b*, cup-shaped pharyngeal cavity; *c*, single dorsal ocellus; *d*, *d*, cells of deep cutaneous layer (?).

XXII. *On the Tides of the Arctic Seas.*

By the Rev. Samuel Haughton, *M.D., F.R.S., Fellow of Trinity College, Dublin.*

Part III. *On the Semidiurnal Tides of Frederiksdal, near Cape Farewell, in Greenland.*

Received April 12,—Read April 26, 1866.

I am indebted, for the opportunity of laying the following observations and their discussion before the Royal Society, to the kindness and courtesy of Chamberlain General Adjutant Irminger, of the Royal Danish Navy, who undertook (in 1862) to have Tidal observations made by the Missionaries and Government officers at certain stations on the coast of Greenland, for the purpose of completing the observations, on the Tides of the Arctic Seas, made by several officers of Her Majesty's Navy during the search for Sir John Franklin; some of which I have already laid before the Society, in Parts I. and II. of these papers; of others I hope to be able to complete the discussion, and to forward them in due course to the Royal Society.

The observations recorded and discussed in the present paper were made in 1863–64, at Frederiksdal, near Cape Farewell, by Missionary Asboe, to whom and to Admiral Irminger I beg leave to return my warmest thanks for their uniform courtesy and attention to a request proceeding from a total stranger.

Frederiksdal is situated in the South of Greenland, about 37 miles W. and by N. from Cape Farewell, and is the nearest station to this Cape at which tidal observations can be made. It is in lat. 60° N., and long. 45° W. from Greenwich.

The observations were made on one High and one Low water each day, from August 1863 to August 1864, with occasional interruptions caused by ice and by more pressing public duties. They have proved to be abundantly sufficient for the determination of the laws of the Semidiurnal Tides, and of the important inferences deducible from them.

My first step in the discussion was to form the following Tables, which contain the materials used subsequently in the paper.

Table I.—Semidiurnal Maximum Spring Ranges of the Tide at Frederiksdal in 1863–64, with the Hour-Angles of the Sun and Moon, on the days on which the Maximum Ranges occurred.

No.	Date.	Sun's Hour-Angle.	Moon's Hour-Angle.	Range.	Difference.
		h m	h m	ft.	ft.
1	1863. Aug. 30.	7 0	3 1	8·8	
2	„ Sept. 17.	9 12	2 53	8·7	0·1
3	„ Sept. 29.	7 13	2 53	10·1	1·4
4	„ Oct. 15.	8 0	2 51	9·5	0·6
5	„ Nov. 28.	8 0	2 54	8·5	
6	„ Dec. 13.	8 32	2 52	9·6	1·1
7	„ Dec. 28.	8 12	2 52	9·4	0·2
8	1864. Jan. 12.	9 5	2 52	10·0	0·6
9	„ Feb. 25.	7 55	3 5	10·3	
10	„ Mar. 10.	8 8	2 52	10·7	0·4
11	„ Mar. 25.	7 15	2 58	10·3	0·4
12	„ April 8.	7 57	3 9	10·2	0·1
13	„ May 24.	8 15	2 52	10·2	
14	„ June 4.	5 58	2 52	8·8	1·4
15	„ June 20.	6 41	3 31	8·7	0·1
16	„ July 4.	6 25	2 53	8·0	0·7
17	„ July 19.	6 35	3 29	9·0	1·0
18	„ Aug. 3.	6 54	3 8	8·4	0·6
19	„ Aug. 19.	7 15	2 52	9·5	1·1
	Means......	7 36	2 59	9·40	

Table II.—Semidiurnal Minimum Neap Ranges of the Tides at Frederiksdal in 1863–64, with the Hour-Angles of the Sun and Moon, on the days on which the Minimum Ranges occurred.

No.	Date.	Sun's Hour-Angle.	Moon's Hour-Angle.	Range.	Difference.
		h m	h m	ft.	ft.
1	1863. Aug. 23.	12 45	2 29	3·8	
2	„ Sept. 6.	12 48	2 55	3·0	0·8
3	„ Sept. 21.	12 50	1 44	4·4	1·4
4	„ Oct. 5.	12 53	3 31	3·5	0·9
5	„ Oct. 20.	12 40	2 47	5·0	1·5
6	„ Dec. 5.	1 0	2 45	4·3	
7	„ Dec. 21.	3 13	2 45	4·6	0·3
8	1864. Jan. 3.	12 31	2 52	4·7	0·1
9	„ Jan. 18.	2 8	2 52	5·1	0·4
10	„ Mar. 2.	12 40	2 53	5·3	
11	„ Mar. 18.	2 50	2 53	4·3	1·0
12	„ April 1.	1 15	2 44	4·7	0·4
13	„ April 16.	2 11	2 52	3·6	1·1
14	„ May 29.	12 57	3 3	5·6	
15	„ June 12.	12 10	2 55	4·3	1·3
16	„ June 28.	1 16	2 43	4·1	0·2
17	„ July 13.	1 2	2 53	4·6	0·5
18	„ July 28.	1 43	2 47	5·8	1·2
19	„ Aug. 12.	1 36	2 59	5·0	0·8
	Means......	1 14	2 48	4·51	

The Ranges of Spring and Neap Tides contained in the following Tables, are laid down on the diagram (p. 643), which is intended to show the Parallactic Inequality deducible from the observations. This Inequality may be also found from the columns of differences of Ranges given in Tables I. and II.

It appears, both from the diagram and from the Tables, that the maximum amount of this Inequality, plus and minus, is 1·4 foot.

The expression for the Tidal Range is

$$R=2S\left(\frac{P}{P_m}\right)^3\cos^2\sigma\cos 2(s-i_s)+2M\left(\frac{p}{p_m}\right)^3\cos^2\mu\cos 2(m-i_m), \quad . \quad . \quad . \quad . \quad (1)$$

where

S and M are the Solar and Lunar coefficients.

P and p the Solar and Lunar parallax; and P_m, p_m the mean values of the same.

σ, μ, the declinations of Sun and Moon.

s, m, the hour-angles of Sun and Moon.

i_s, i_m, the Solitidal and Lunitidal intervals.

As the Sun's declination may be regarded as constant for a fortnight, and as the Moon's declination only changes sign in that period, it is plain that the differences of successive spring and neap ranges are due altogether to the parallactic inequality.

The Solar and Lunar coefficients are found as follows. When the observations are spread over an entire year, as in the present case, the means of all the spring and neap ranges give the sum and difference of the Lunar and Solar Tides, cleared of parallax and referred to the mean declinations of the Sun and Moon—that is, to their declinations at 45° from the intersection of their orbits with the equinoctial.

Let σ_m and μ_m denote these declinations; then we have

$$\left.\begin{aligned}\sin\sigma_m &= \sin 45^\circ\times\sin 23^\circ\,28' = \sin(16^\circ\,21')\\ \sin\mu_m &= \sin 45^\circ\times\sin 20^\circ \quad\;\; = \sin(14^\circ)\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Using these values of σ_m and μ_m, we obtain from Tables I. and II.

$$2M\cos^2(14^\circ)+2S\cos^2(16^\circ\,21')=9{\cdot}40 \text{ feet},$$
$$2M\cos^2(14^\circ)-2S\cos^2(16^\circ\,21')=4{\cdot}51 \text{ feet},$$

or

$$\left.\begin{aligned}4M\cos^2(14^\circ) \quad\quad &=13{\cdot}91 \text{ feet},\\ 4S\;\cos^2(16^\circ\,21') &=\;4{\cdot}89 \text{ feet}.\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From which we obtain, finally,

$$M=3{\cdot}693 \text{ feet} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{I.})$$
$$S=1{\cdot}328 \text{ feet} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{II.})$$

The Lunitidal and Solitidal Intervals are found from the means of the hour-angles given in Tables I. and II., and are

	h	m
Lunitidal interval at Springs	2	59
Lunitidal interval at Neaps	2	48
Mean	2	53½

	h	m
Solitidal interval at Springs	7	36
Solitidal interval at Neaps	7	14
Mean	7	25

Hence we find

$$i_m = 2^{\mathrm{h}}\ 53\tfrac{1}{2}^{\mathrm{m}} \quad \dots\dots\dots\dots \quad \text{(III.)}$$

$$i_s = 7^{\mathrm{h}}\ 25^{\mathrm{m}} \quad \dots\dots\dots\dots \quad \text{(IV.)}$$

We are now in a condition to calculate, according to received theories, from the preceding data, the eccentricity of the Moon's path, her mass as compared with that of the earth, and the mean depth of the ocean canal traversed by the tide previously to its reaching Frederiksdal.

1. *Eccentricity of the Lunar Orbit.*

It appears from equations (3) that the mean height of the High Water of the Lunar Tide is

$$\mathrm{M}\cos^2(14^\circ) = \frac{13{\cdot}91}{4} = 3{\cdot}477 \text{ feet.}$$

Adding to this, and subtracting from it half the maximum parallactic inequality, we obtain, with the aid of equation (1),

$$\left(\frac{1+e}{1-e}\right)^3 = \frac{3{\cdot}48+0{\cdot}70}{3{\cdot}48-0{\cdot}70} = \frac{4{\cdot}18}{2{\cdot}78},$$

or

$$\frac{1+e}{1-e} = 1{\cdot}1456;$$

and, finally,

$$e = \frac{1456}{21456} = 0{\cdot}06786. \quad \dots\dots\dots\dots \quad \text{(V.)}$$

2. *Mass of the Moon.*

The ratio of the mass of the Earth to the mass of the Moon is found from the equation

$$\frac{\text{Mass of Earth}}{\text{Mass of Moon}} = \frac{\text{Mass of Earth}}{\text{Mass of Sun}} \times \frac{\text{Mass of Sun}}{\text{Mass of Moon}} = \frac{1}{359551} \times \left(\frac{2 \times 12032}{59{\cdot}964}\right)^3 \times \frac{\mathrm{S}}{\mathrm{M}}, \quad . \quad . \quad (4)$$

or

$$\frac{\text{Mass of Earth}}{\text{Mass of Moon}} = 179{\cdot}75 \times \frac{\mathrm{S}}{\mathrm{M}} = 179{\cdot}75 \times \frac{1328}{3693};$$

and, finally,

$$\frac{\text{Mass of Earth}}{\text{Mass of Moon}} = 64{\cdot}638. \quad \dots\dots\dots\dots \quad \text{(VI.)}$$

3. *Depth of the Sea deduced from Heights.*

The depth of the Sea, determined from heights, is found from the equation

$$\frac{\mathrm{S}}{\mathrm{M}} = 0{\cdot}47288 \times \frac{12{\cdot}778-k}{13{\cdot}648-k}. \quad \dots\dots\dots\dots \quad (5)$$

Substituting for 2S and 2M their values 1328 and 3693, we find

$$1328\ (13{\cdot}648-k)=0{\cdot}47288\times 3693(12{\cdot}778-k),$$

or

$$k=\frac{22315-18124}{1746-1328}=10{\cdot}03 \text{ miles.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(VII.)}$$

4. *Depth of the Sea deduced from Times.*

The depth of the sea derivable from the retardation of times caused by friction, is given by the equation

$$\frac{\text{Lunitidal Acceleration}}{\text{Solitidal Acceleration}}=\frac{13{\cdot}815-4k}{12{\cdot}938-4k}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

But, from (III.) and (IV.), we have

$$\text{Lunitidal Acceleration}=6^{\text{h}}\ 12^{\text{m}}-2^{\text{h}}\ 53^{\text{m}}=+199^{\text{m}},$$

$$\text{Solitidal Acceleration}\ =6\quad 0-7\quad 25=-\ 85.$$

Hence we find

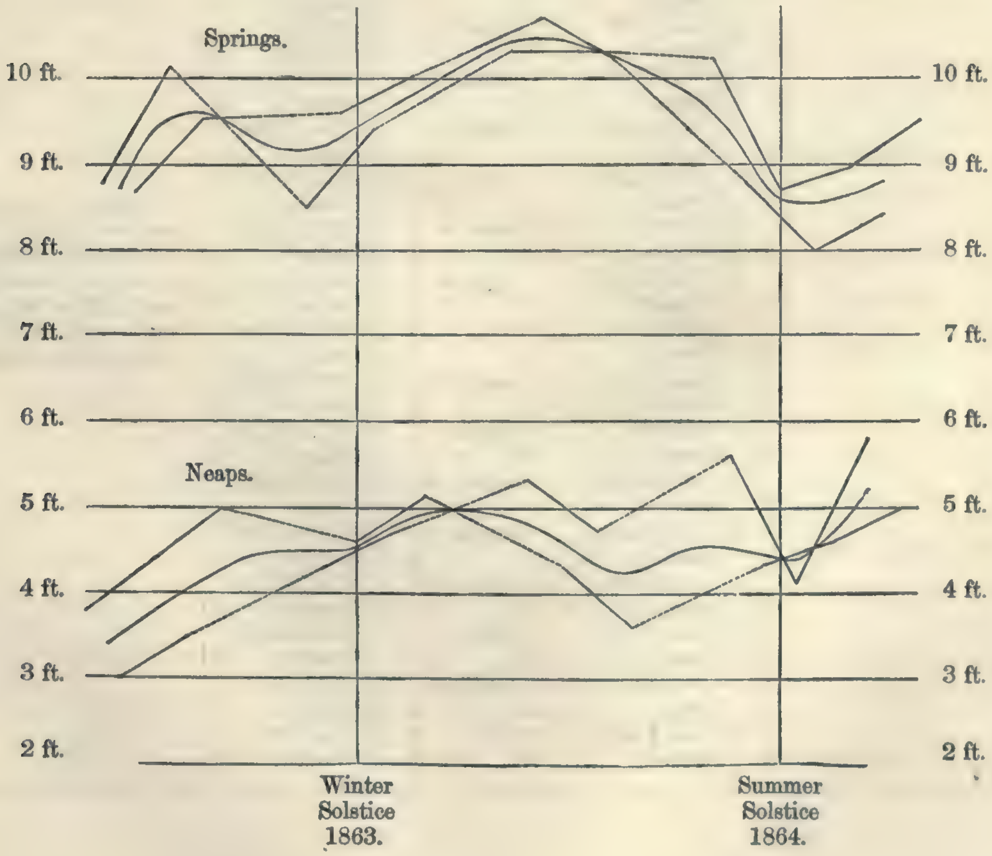
$$-\frac{199}{85}=\frac{13{\cdot}815-4k}{12{\cdot}938-4k},$$

and

$$4k=\frac{3748{\cdot}937}{284}=13{\cdot}200 \text{ miles,}$$

$$k=3{\cdot}30 \text{ miles,} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(VIII.)}$$

Parallactic Inequality at Frederiksdal, 1863–64.



Det nærmeste Sted ved Cap Farvel, hvor Jagttagelser kan foretages.

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
			Kl. 11.55	over 0		Kl. 6	Den 14de August 1863 da Mærket til Opservationen af Havets Falden og Stigen hersteds Elev sat fandtes den laveste Vandstand, der betegnedes med 0, Kl. 11.55 om Formiddagen Sted; senere Elev et lavere Mærke nödvendig, og de derpaa anbragte Fod og Tommer gjelder een Gang for alle *under* 0. Den egentlige Opservation begyndte först den 22de August.
1863. Aug. 22.	6	0	Frmd.	1	9	Eftmd.	
			Kl. 12.45	over 0		Kl. 6.46	
23.	5	10	Eftmd.	1	10	Frmd.	
			Kl. 1.36	over 0		Kl. 7.40	
24.	6	3	Eftmd.	1	10	Frmd.	
			Kl. 2.25	over 0		Kl. 8.50	
25.	6	9	Eftmd.	1	6	Frmd.	
			Kl. 3.40	over 0		Kl. 9.45	
26.	7	3	Eftmd.	1	0	Frmd.	
			Kl. 4.38	0		Kl. 10.45	
27.	7	9	Eftmd.	0	6	Frmd.	
			Kl. 5.40	under 0		Kl. 11.40	
28.	8	1	Eftmd.	0	1	Frmd.	
			Kl. 6. 1	under 0		Kl. 12. 3	
29.	8	3	Frmd.	0	8	Eftmd.	
			Kl. 7	under 0		Kl. 12.56	
30.	7	9	Frmd.	1	2	Eftmd.	
			Kl. 7.40	under 0		Kl. 1.48	
31.	7	8	Frmd.	1	1	Eftmd.	
			Kl. 8.35	under 0		Kl. 2.38	These observations are from Frederiksdal, in the neighbourhood of Cape Farewell, in about 60° latitude and 44½° west of Greenwich.—C. Irminger.
Sept. 1.	7	1	Frmd.	1	0	Eftmd.	
			Kl. 9.20	under 0		Kl. 3.29	
2.	6	9	Frmd.	0	8	Eftmd.	
			Kl. 10.12	under 0		Kl. 4.19	
3.	6	6	Frmd.	0	4	Eftmd.	
			Kl. 11. 5	under 0		Kl. 5.10	
4.	6	0	Frmd.	0	2	Eftmd.	
			Kl. 11.50	over 0		Kl. 6	
5.	5	6	Frmd.	1	9	Eftmd.	
			Kl. 12.48	over 0		Kl. 6.50	
6.	5	1	Eftmd.	1	7	Frmd.	
			Kl. 1.36	over 0		Kl. 7.38	
7.	5	4	Eftmd.	1	10	Frmd.	
			Kl. 2.20	over 0		Kl. 8.25	
8.	5	5	Eftmd.	1	5	Frmd.	
			Kl. 3. 5	over 0		Kl. 9.10	
9.	5	8	Eftmd.	1	3	Frmd.	
			Kl. 3.53	over 0		Kl. 9.54	
10.	6	7	Eftmd.	0	7	Frmd.	
			Kl. 4.35			Kl. 10.38	
11.	6	9	Eftmd.	0	0	Frmd.	
			Kl. 5.16	under 0		Kl. 11.21	
12.	7	0	Efmtd.	0	6	Frmd.	
			Kl. 6	under 0		Kl. 12. 5	
13.	7	5	Frmd.	0	11	Eftmd.	
			Kl. 6.45	under 0		Kl. 12.49	
14.	7	2	Frmd.	1	0	Eftmd.	
			Kl. 7.32	under 0		Kl. 1.36	
15.	7	4	Frmd.	1	6	Eftmd.	
			Kl. 8.20	under 0		Kl. 2.25	
16.	7	7	Frmd.	1	5	Eftmd.	
			Kl. 9.12	under 0		Kl. 3.16	
17.	7	6	Frmd.	0	11	Eftmd.	
			Kl. 10. 5	under 0		Kl. 4.10	
18.	7	1	Frmd.	0	5	Eftmd.	
			Kl. 10.55	0	0	Kl. 5	
19.	6	8	Frmd.	0	0	Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
			Kl. 11.55	over 0		Kl. 6. 5	
1863. Sept. 20.	6	2	Frmd.	0	6	Eftmd.	
			Kl. 12.50	over 0		Kl. 7. 3	
21.	5	9	Eftmd.	0	8	Frmd.	Sönden Vind.
			Kl. 1.55	over 0		Kl. 8. 1	
22.	6	2	Eftmd.	1	0	Frmd.	Do. Storm.
			Kl. 2.52	over 0		Kl. 8.56	
23.	6	5	Eftmd.	1	2	Frmd.	Norden do.
			Kl. 3.45	over 0		Kl. 9.50	
24.	6	10	Eftmd.	0	8	Frmd.	Do. do.
			Kl. 4.38	0	0	Kl. 10.42	
25.	7	2	Eftmd.	0	0	Frmd.	Do. no.
			Kl. 5.30	under 0		Kl. 11.34	
26.	7	9	Etfmd.	0	8	Frmd.	Do. do.
			Kl. 5.50	under		Kl. 11.57	
27.	7	8	Etfmd.	1	4	Frmd.	Do. do.
			Kl. 6.20	under 0		Kl. 12.25	
28.	7	10	Frmd.	1	10	Eftmd.	Do. do.
			Kl. 7.13			Kl. 1.17	
29.	8	2	Frmd.	1	11	Eftmd.	Do. do.
			Kl. 8. 3	under 0		Kl. 2. 8	
30.	8	0	Frmd.	0	9	Eftmd.	Do. do.
			Kl. 8.54	under 0		Kl. 3	
Oct. 1.	7	8	Frmd.	0	1	Eftmd.	Do. do.
			Kl. 9.50	over 0		Kl. 3.51	
2.	7	1	Frmd.	0	4	Eftmd.	
			Kl. 10.38	over 0		Kl. 4.42	
3.	6	7	Frmd.	1	0	Eftmd.	
			Kl. 11.27	over 0		Kl. 5.31	
4.	5	11	Frmd.	1	6	Eftmd.	
			Kl. 12.15	over 0		Kl. 6.19	
5.	5	6	Eftmd.	1	9	Frmd.	
			Kl. 1	over 0		Kl. 7. 5	
6.	6	0	Eftmd.	2	1	Frmd.	Sönden Storm.
			Kl. 1.54	over 0		Kl. 7.49	
7.	5	6	Eftmd.	2	0	Frmd.	
			Kl. 2.40	over 0		Kl. 8.33	
8.	5	8	Eftmd.	1	6	Frmd.	
			Kl. 3.12	over 0		Kl. 9.16	
9.	5	10	Eftmd.	1	0	Frmd.	
			Kl. 4	over 0		Kl. 10	
10.	6	5	Eftmd.	0	9	Frmd.	
			Kl. 4.40	over 0		Kl. 10.44	
11.	7	0	Eftmd.	0	3	Frmd.	
			Kl. 5.26	under 0		Kl. 11.31	
12.	7	4	Eftmd.	0	5	Frmd.	
			Kl. 6.15	under 0		Kl. 12.19	
13.	7	10	Frmd.	0	8	Eftmd.	
			Kl. 7.6	under 0		Kl. 1.11	
14.	8	0	Frmd.	0	10	Eftmd.	
			Kl. 8	under 0		Kl. 2. 6	
15.	8	6	Frmd.	1	0	Eftmd.	
			Kl. 9	under		Kl. 3. 2	
16.	7	8	Frmd.	0	6	Eftmd.	
			Kl. 9.54	under 0		Kl. 4. 1	
17.	7	3	Frmd.	0	2	Eftmd.	
			Kl. 10.50	over 0		Kl. 4.59	
18.	7	2	Frmd.	0	8	Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
			Kl. 11.48	over 0		Kl. 5.55	
1863. Oct. 19.	6	8	Frmd.	1	3	Eftmd.	
			Kl. 12.40	over 0		Kl. 6.50	
20.	6	2	Eftmd.	1	9	Frmd.	
			Kl. 1.25			Kl. 7.30	
21.	6	6	Eftmd.	1	0	Frmd.	
			Kl. 2.54	over 0		Kl. 8.59	
Nov. 21.	7	4	Eftmd.	2	0	Frmd.	Sönden Storm.
			Kl. 3.43	over 0		Kl. 9.48	
22.	7	6	Eftmd.	1	7	Frmd.	
			Kl. 4.34	over 0		Kl. 10.39	
23.	7	4	Eftmd.	1	6	Frmd.	
			Kl. 5.26	over 0		Kl. 11.31	
24.	7	6	Eftmd.	1	5	Frmd.	
			Kl. 5.50	over 0		Kl. 11.50	
25.	7	8	Eftmd.	1	0	Frmd.	
			Kl. 6.17	over 0		Kl. 12.22	
26.	8	0	Frmd.			Eftmd.	
			Kl. 7. 8	0	0	Kl. 1.13	
27.	8	2	Frmd.	0	0	Eftmd.	
			Kl. 8	under		Kl. 2. 3	
28.	8	4	Frmd.	0	2	Eftmd.	
			Kl. 8.48	under 0		Kl. 2.51	
29.	8	0	Frmd.	0	4	Eftmd.	
			Kl. 9·32	over 0		Kl. 3.37	
30.	7	10	Frmd.	0	2	Eftmd.	Næsten ukjændelig for Fis.
			Kl. 10.16	over 0		Kl. 4.21	
Dec. 1.	7	6	Frmd.	0	6	Eftmd.	12–14 Gr. Kuldet.
			Kl. 11	over 0		Kl. 5. 4	
2.	7	0	Frmd.	0	8	Eftmd.	Do. do.
			Kl. 11.40	over 0		Kl. 5.46	
3.	6	6	Frmd.	1	2	Eftmd.	Do. do.
			Kl. 12.24	over 0		Kl. 6.29	
4.	6	0	Eftmd.	1	8	Frmd.	Do. do.
			Kl. 1. 7	over 0		Kl. 7.12	
5.	6	2	Eftmd.	1	11	Frmd.	
			Kl. 1.55	over 0		Kl. 7.58	
6.	6	8	Eftmd.	2	1	Frmd.	
			Kl. 2.40	over 0		Kl. 8.47	
7.	7	1	Eftmd.	1	8	Frmd.	
			Kl. 3.34	over 0		Kl. 9.39	
8.	7	5	Eftmd.	1	0	Frmd.	
			Kl. 4.30	over 0		Kl. 10.35	
9.	7	6	Eftmd.	0	4	Frmd.	
			Kl. 5.30	under 0		Kl. 11.35	
10.	7	8	Eftmd.	0	4	Frmd.	
			Kl. 6.32	under 0		Kl. 12.37	
11.	7	10	Frmd.	0	6	Eftmd.	
			Kl. 7.33	under 0		Kl. 1.38	
12.	8	0	Frmd.	1	0	Eftmd.	
			Kl. 8.32	under 0		Kl. 2.37	
13.	8	0	Frmd.	2	0	Eftmd.	
			Kl. 9.28	under		Kl. 3.34	
14.	7	6	Frmd.	1	6	Eftmd.	
			Kl. 10.22	under 0		Kl. 4.27	
15.	7	2	Frmd.	1	2	Eftmd.	
			Kl. 11.13	under 0		Kl. 5.18	
16.	7	0	Frmd.	1	0	Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
Dec. 17.	7	0	Kl. 12 Frmd.	under 0 0	6	Kl. 6. 8 Eftmd.	
18.	6	6	Kl. 12.54 Eftmd.	under 0 0	1	Kl. 6.57 Frmd.	
19.	6	0	Kl. 1.41 Eftmd.	over 0 0	6	Kl. 7.46 Frmd.	
20.	5	10	Kl. 2.30 Eftmd.	over 0 0	10	Kl. 8.35 Frmd.	
21.	6	1	Kl. 3.20 Eftmd.	over 0 1	5	Kl. 9.25 Frmd.	
22.	6	4	Kl. 4.11 Eftmd.	over 0 1	6	Kl. 10.16 Frmd.	
23.	6	8	Kl. 5. 2 Eftmd.	over 0 1	0	Kl. 11. 7 Frmd.	
24.	6	11	Kl. 5.52 Eftmd.	over 0 0	4	Kl. 11.57 Frmd.	
25.	7	6	Kl. 6.35 Frmd.	under 0 0	2	Kl. 12.40 Eftmd.	
26.	8	0	Kl. 6.41 Frmd.	under 0 0	6	Kl. 12.46 Eftmd.	
27.	8	4	Kl. 7.27 Frmd.	under 0 0	8	Kl. 1.32 Eftmd.	
28.	8	5	Kl. 8.12 Frmd.	undar 0 1	2	Kl. 2.17 Eftmd.	
29.	7	10	Kl. 9 Frmd.	under 0 0	7	Kl. 3. 5 Eftmd.	
30.	6	3	Kl. 9.41 Frmd.	under 0 0	4	Kl. 3.46 Eftmd.	
31.	5	9	Kl. 10.20 Frmd.	over 0 0	6	Kl. 4.25 Eftmd.	
1864. Jan. 1.	5	4	Kl. 11. 2 Frmd.	over 0 0	2	Kl. 5. 7 Eftmd.	
2.	5	0	Kl. 11.50 Frmd.	over 0 0	3	Kl. 5.51 Eftmd.	
3.	5	5	Kl. 12.31 Eftmd.	over 0 0	2	Kl. 6.36 Frmd.	
4.	5	11	Kl. 1.20 Eftmd.	over 0 0	1	Kl. 7.25 Frmd.	
5.	6	4	Kl. 2.13 Eftmd.	under 0 0	2	Kl. 8.18 Frmd.	
6.	6	10	Kl. 3.10 Eftmd.	under 0 0	5	Kl. 9.15 Frmd.	
7.	7	0	Kl. 4.10 Eftmd.	under 0 0	8	Kl. 10.15 Frmd.	
8.	7	4	Kl. 5.12 Eftmd.	under 0 0	10	Kl. 11.17 Frmd.	
9.	7	8	Kl. 6.14 Frmd.	under 0 0	11	Kl. 12.19 Eftmd.	
10.	8	0	Kl. 7.14 Frmd.	under 0 1	1	Kl. 1.19 Eftmd.	
11.	8	2	Kl. 8.11 Frmd.	under 0 1	3	Kl. 2.16 Eftmd.	
12.	8	4	Kl. 9. 5 Frmd.	under 0 1	8	Kl. 3.10 Eftmd.	
13.	7	8	Kl. 10 Frmd.	under 0 1	6	Kl. 4. 2 Eftmd.	
14.	7	3	Kl. 10.50 Frmd.	1	7	Kl. 4.53 Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
1864. Jan. 15.	7	2	Kl. 11.38 Frmd.	under 0 1	0	Kl. 5.43 Eftmd.	
16.	6	8	Kl. 12.34 Eftmd.	under 0 0	6	Kl. 6.40 Frmd.	
17.	6	2	Kl. 1.18 Eftmd.	under 0 0	0	Kl. 7.23 Frmd.	
18.	5	8	Kl. 2. 8 Eftmd.	over 0 0	5	Kl. 8.13 Frmd.	
19.	5	10	Kl. 3 Eftmd.	over 0 0	10	Kl. 9. 4 Frmd.	
20.	6	2	Kl. 3.48 Eftmd.	over 0 1	0	Kl. 9.53 Frmd.	
21.	6	7	Kl. 4.40 Eftmd.	over 0 0	6	Kl. 10.42 Frmd.	
22.	7	0	Kl. 5.24 Eftmd.	over 0 0	0	Kl. 11.29 Frmd.	
Feb. 21.	7	5	Kl. 5.35 Eftmd.	under 0 0	6	Kl. 11.40 Frmd.	
22.	7	4	Kl. 6.25 Frmd.	under 0 0	10	Kl. 12.30 Eftmd.	
23.	7	6	Kl. 6.49 Frmd.	under 0 1	5	Kl. 12.50 Eftmd.	
24.	7	11	Kl. 7.15 Frmd.	under 0 1	10	Kl. 1.20 Eftmd.	
25.	8	2	Kl. 7.55 Frmd.	under 0 2	1	Kl. 2 Eftmd.	
26.	8	0	Kl. 8.40 Frmd.	under 0 1	10	Kl. 2.41 Eftmd.	
27.	7	7	Kl. 9.15 Frmd.	under 0 1	5	Kl. 3.20 Eftmd.	
28.	7	1	Kl. 10. 3 Frmd.	under 0 0	11	Kl. 4. 8 Eftmd.	
29.	6	8	Kl. 10.50 Frmd.	under 0 0	5	Kl. 4.55 Eftmd.	
Marts 1.	6	3	Kl. 11.53 Frmd.	under 0 0	0	Kl. 5.58 Eftmd.	Neden for Undertegned tör nokindestaa for Jagttagelsens Rigtighed med Undtagelse af Vintermaanederne, hvor det som oftest Elev höist vanskeligt, for Driv- og Tyndisens Skyld, atfaa nöie Kjendning af Lavvende ligsom det var Tilfældet med Höivande for Fiskantens Skyld.
2.	5	10	Kl. 12.40 Eftmd.	over 0 0	0	Kl. 6.44 Frmd.	
3.	6	0	Kl. 1.37 Eftmd.	over 6 0	2	Kl. 7.42 Frmd.	
4.	6	5	Kl. 2.34 Eftmd.	over 0 0	0	Kl. 8.40 Frmd.	
5.	6	9	Kl. 3.35 Eftmd.	under 0 0	6	Kl. 9.38 Frmd.	
6.	7	2	Kl. 4.30 Eftmd.	under 0 1	0	Kl. 10.35 Frmd.	
7.	7	7	Kl. 5.26 Eftmd.	under 0 1	5	Kl. 11.31 Frmd.	
8.	7	11	Kl. 6.20 Frmd.	under 0 1	9	Kl. 12.25 Eftmd.	
9.	8	2	Kl. 7.15 Frmd.	under 0 1	11	Kl. 1.19 Eftmd.	
10.	8	5	Kl. 8. 8 Frmd.	under 0 2	4	Kl. 2.13 Eftmd.	
11.	8	6	Kl. 9. 1 Frmd.	under 0 2	3	Kl. 3. 6 Eftmd.	
12.	8	0	Kl. 9.54 Frmd.	under 0 1	9	Kl. 3.59 Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
1864. Marts 13.	7	6	Kl. 10.47 Frmd.	under 0 1	3	Kl. 4.52 Eftmd.	
14.	7	0	Kl. 11.39 Frmd.	under 0 0	9	Kl. 5.44 Eftmd.	
15.	6	7	Kl. 12.29 Eftmd.	under 0 0	3	Kl. 6.34 Frmd.	
16.	6	2	Kl. 1.18 Eftmd.	over 0 0	0	Kl. 7.23 Frmd.	
17.	5	9	Kl. 2. 4 Eftmd.	over 0 0	6	Kl. 8. 9 Frmd.	
18.	5	4	Kl. 2.50 Eftmd.	over 0 1	0	Kl. 8.54 Frmd.	
19.	5	10	Kl. 3.33 Eftmd.	over 0 0	10	Kl. 9.38 Frmd.	
20.	6	4	Kl. 4.15 Eftmd.	over 0 0	3	Kl. 10.20 Frmd.	
21.	6	9	Kl. 5 Eftmd.	over 0 0	2	Kl. 11. 3 Frmd.	
22.	7	2	Kl. 5.40 Eftmd.	under 0 0	4	Kl. 11.45 Frmd.	
23.	7	7	Kl. 6.25 Frmd.	under 0 0	10	Kl. 12.30 Eftmd.	
24.	8	0	Kl. 6.15 Frmd.	under 0 1	5	Kl. 12.39 Eftmd.	
25.	8	4	Kl. 7.15 Frmd.	under 0 2	1	Kl. 1.20 Eftmd.	
26.	7	11	Kl. 7.57 Frmd.	under 0 1	8	Kl. 2. 2 Eftmd.	
27.	7	6	Kl. 8.50 Frmd.	under 0 1	3	Kl. 2.52 Eftmd.	
28.	7	1	Kl. 9.39 Frmd.	under 0 0	10	Kl. 3.44 Eftmd.	
29.	6	8	Kl. 10.34 Frmd.	under 0	5	Kl. 4.39 Eftmd.	
30.	6	8	Kl. 11.30 Frmd.	under 0 0	0	Kl. 5.35 Eftmd.	
31.	5	11	Kl. 12.26 Eftmd.	over 0 0	5	Kl. 6.31 Frmd.	
April 1.	5	6	Kl. 1.15 Eftmd.	over 0 0	10	Kl. 7.20 Frmd.	
2.	5	10	Kl. 2.13 Eftmd.	over 0 0	6	Kl. 8.18 Frmd.	
3.	6	4	Kl. 3.12 Eftmd.	over 0 0	0	Kl. 9.17 Frmd.	
4.	6	9	Kl. 4. 5 Eftmd.	under 0 0	2	Kl. 10.10 Frmd.	
5.	7	3	Kl. 5 Eftmd.	under 0 0	6	Kl. 11. 4 Frmd.	
6.	7	8	Kl. 6.52 Eftmd.	under 0 1	0	Kl. 11.57 Frmd.	
7.	8	0	Kl. 7.46 Frmd.	under 0 1	5	Kl. 12.51 Eftmd.	
8.	8	4	Kl. 7.57 Frmd.	under 0 1	10	Kl. 1.45 Eftmd.	
9.	7	11	Kl. 8.36 Frmd.	under 0 1	5	Kl. 2.39 Eftmd.	
10.	7	6	Kl. 9.28 Frmd.	under 0 1	0	Kl. 3.33 Eftmd.	

TABLE (continued).

Datum.	Höivande. Fod.	Höivande. Tommer.	Klokkeslet Formiddag eller Eftermiddag.	Lavvande. Fod.	Lavvande. Tommer.	Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
1864. April 11.	7	1	Kl. 10.20 Frmd.	under 0 0	7	Kl. 4.25 Eftmd.	
12.	6	8	Kl. 11.10 Frmd.	under 0 0	2	Kl. 5.15 Eftmd.	
13.	6	3	Kl. 12. 1 Eftmd.	over 0 0	3	Kl. 6. 3 Frmd.	
14.	5	11	Kl. 12.50 Eftmd.	over 0 0	8	Kl. 6.49 Frmd.	
15.	5	6	Kl. 1.30 Eftmd.	over 0 1	1	Kl. 7.33 Frmd.	
16.	5	1	Kl. 2.11 Eftmd.	over 0 1	6	Kl. 8.16 Frmd.	
17.	5	6	Kl. 2.54 Eftmd.	over 0 1	1	Kl. 8.59 Frmd.	
18.	5	11	Kl. 3.36 Eftmd.	over 0 0	7	Kl. 9.41 Frmd.	
19.	6	5	Kl. 4.20 Eftmd.	over 0 0	1	Kl. 10.25 Frmd.	
20.	6	11	Kl. 5. 5 Eftmd.	under 0 0	6	Kl. 11.10 Frmd.	
21.	7	4	Kl. 5.54 Eftmd.	under 0 1	0	Kl. 11.57 Frmd.	
22.	7	9	Kl. 6.42 Frmd.	under 0 1	6	Kl. 12.47 Eftmd.	
Mai 21.	7	4	Kl. 5.33 Eftmd.	under 0 1	4	Kl. 11.30 Frmd.	
22.	7	8	Kl. 6.20 Frmd.	under 0 1	8	Kl. 12.25 Eftmd.	
23.	7	10	Kl. 7.18 Frmd.	under 0 2	0	Kl. 1.22 Eftmd.	
24.	8	2	Kl. 8.15 Frmd.	under 0 2	0	Kl. 2.20 Eftmd.	
25.	7	6	Kl. 9.13 Frmd.	under 0 1	6	Kl. 3.18 Eftmd.	Sönden Storm.
26.	6	0	Kl. 10. 9 Frmd.	under 0 0	10	Kl. 4.14 Eftmd.	
27.	5	7	Kl. 11. 3 Frmd.	under 0 0	6	Kl. 5. 3 Eftmd.	
28.	5	4	Kl. 12. 1 Eftmd.	under 0 0	4	Kl. 6 Frmd.	
29.	5	0	Kl. 12.57 Eftmd.	under 0 0	6	Kl. 6.51 Frmd.	
30.	5	0	Kl. 1.47 Eftmd.	under 0 0	7	Kl. 7.41 Frmd.	Heraf sees at Lavvande i denne Tid er betydeliger end Höivande, nemlig forholdsmæssig.
31.	5	6	Kl. 2.40 Eftmd.	under 0 1	0	Kl. 8.32 Frmd.	
Juni 1.	6	4	Kl. 3.30 Eftmd.	under 0 0	6	Kl. 9.24 Frmd.	
2.	7	0	Kl. 4.21 Eftmd.	under 0 1	0	Kl. 10.16 Frmd.	Sönden Storm.
3.	7	5	Kl. 5.15 Eftmd.	under 0 1	2	Kl. 11.10 Frmd.	Sönden Storm.
4.	7	6	Kl. 5.58 Frmd.	under 0 1	4	Kl. 12. 3 Eftmd.	
5.	6	6	Kl. 6.50 Frmd.	under 0 1	9	Kl. 12.56 Eftmd.	Her bemærkes, hvad derforövrigt er bekjenett, at Vandstanden med ny-
6.	6	0	Kl. 7.32 Frmd.	under 0 2	0	Kl. 1.47 Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
			Kl. 8.22	under 0		Kl. 2.35	og fuld-Maane og et par Dage derefter, er langt betydeligere om Aftenen end om Morgenen, altsaa Höivande höiere og Lavvande lavere.
1864. Juni 7.	6	6	Frmd.	1	6	Eftmd.	
			Kl. 9.17	under 0		Kl. 3.22	
8.	6	5	Frmd.	1	2	Eftmd.	
			Kl. 10	over 0		Kl. 4. 6	
9.	6	0	Frmd.	0	10	Eftmd.	
			Kl. 10.45	over 0		Kl. 4.49	
10.	5	0	Frmd.	0	9	Eftmd.	
			Kl. 11.34	over 0		Kl. 5.31	
11.	5	2	Frmd.	0	11	Eftmd.	
			Kl. 12.10	over 0		Kl. 6. 8	
12.	5	4	Eftmd.	1	0	Frmd.	
			Kl. 12.58	over 0		Kl. 6.56	
13.	5	10	Eftmd.	0	6	Frmd.	
			Kl. 2.20	over 0		Kl. 7.40	
14.	5	4	Eftmd.	0	3	Frmd.	
			Kl. 3	over 0		Kl. 8.27	
15.	5	4	Eftmd.	0	4	Frmd.	
			Kl. 3.45	over 0		Kl. 9.17	
16.	5	6	Eftmd.	0	0	Frmd.	
			Kl. 4.30	under 0		Kl. 10. 9	
17.	6	11	Eftmd.	0	2	Frmd.	
			Kl. 5.15	under 0		Kl. 11. 8	
18.	7	4	Eftmd.	0	7	Frmd.	
			Kl. 6. 5	under 0		Kl. 11.56	
19.	7	9	Eftmd.	1	0	Frmd.	
			Kl. 6.41	under 0		Kl. 12.46	
20.	7	3	Frmd.	1	3	Eftmd.	
			Kl. 7.29	under 0		Kl. 1.35	
21.	6	9	Frmd.	1	5	Eftmd.	
			Kl. 8.5	under 0		Kl. 2.10	
22.	6	5	Frmd.	1	0	Eftmd.	
			Kl. 9	under 0		Kl. 3. 1	
23.	6	2	Frmd.	0	8	Eftmd.	
			Kl. 9.50	under 0		Kl. 3.56	
24.	6	0	Frmd.	0	4	Eftmd.	
			Kl. 10.36	under 0		Kl. 4.45	
25.	6	0	Frmd.	0	0	Eftmd.	
			Kl. 11.28	over 0		Kl. 5.39	
26.	5	9	Frmd.	0	3	Eftmd.	
			Kl. 12.25	over 0		Kl. 6.30	
27.	5	5	Eftmd.	0	7	Frmd.	
			Kl. 1.16	over 0		Kl. 7.21	
28.	5	1	Eftmd.	0	11	Frmd.	
			Kl. 2.10	over 0		Kl. 8.12	
29.	5	6	Eftmd.	0	4	Frmd.	
			Kl. 3.10	over 0		Kl. 9. 4	
30.	6	3	Eftmd.	0	9	Frmd.	
			Kl. 3.58	over 0		Kl. 9.57	
Juli 1.	6	8	Eftmd.	0	4	Frmd.	
			Kl. 4.50	under 0		Kl. 10.49	
2.	6	10	Eftmd.	0	3	Frmd.	
			Kl. 5.45	under 0		Kl. 11.40	
3.	7	1	Eftmd.	0	10	Frmd.	
			Kl. 6.25	under 0		Kl. 12.29	
4.	6	0	Frmd.	1	0	Eftmd.	
			Kl. 7.12	under 0		Kl. 1.17	
5.	6	0	Frmd.	1	0	Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
1864. Juli 6.	6	0	Kl. 7.58 Frmd.	under 0 1	2	Kl. 2. 2 Eftmd.	
7.	5	10	Kl. 8.40 Frmd.	under 0	8	Kl. 2.45 Eftmd.	
8.	5	5	Kl. 9.20 Frmd.	under 0 0	2	Kl. 3.27 Eftmd.	
9.	5	3	Kl. 10. 5 Frmd.	over 0 0	1	Kl. 4. 9 Eftmd.	
10.	5	4	Kl. 11 Frmd.	over 0 0	3	Kl. 4.51 Eftmd.	
11.	5	4	Kl. 11.40 Frmd.	over 0 0	5	Kl. 5.34 Eftmd.	
12.	5	2	Kl. 12.20 Eftmd.	over 0 0	6	Kl. 6.19 Frmd.	
13.	5	4	Kl. 1. 2 Eftmd.	over 0 0	8	Kl. 7. 7 Frmd.	
14.	5	8	Kl. 1.53 Eftmd.	over 0 0	6	Kl 7.58 Frmd.	
15.	6	2	Kl. 2.57 Eftmd.	over 0 0	2	Kl. 8.52 Frmd.	
16.	6	6	Kl. 3.55 Eftmd.	under 0 0	2	Kl. 9.50 Frmd.	
17.	7	0	Kl. 4.49 Eftmd.	under 0 0	7	Kl. 10.49 Frmd.	
18.	7	6	Kl. 5.40 Eftmd.	under 0 1	0	Kl. 11.40 Frmd.	
19.	8	0	Kl. 6.35 Frmd.	under 0 1	6	Kl. 12.30 Eftmd.	
20.	7	8	Kl. 6.58 Frmd.	under 0 1	10	Kl. 12.58 Eftmd.	
21.	7	10	Kl. 7.42 Frmd.	under 0 2	0	Kl. 1.45 Eftmd.	
22.	7	10	Kl. 8.35 Frmd.	under 0 2	0	Kl. 2.40 Eftmd.	
23.	7	8	Kl. 9.28 Frmd.	under 0 1	10	Kl. 3.33 Eftmd.	
24.	7	4	Kl. 10.20 Frmd.	under 0 1	6	Kl. 4.26 Eftmd.	
25.	7	0	Kl. 11.12 Frmd.	under 0 1	1	Kl. 5.17 Eftmd.	
26.	6	4	Kl. 12.15 Eftmd.	under 0 0	7	Kl. 6. 9 Frmd.	
27.	5	10	Kl. 12.58 Eftmd.	under 0 0	1	Kl. 7. 1 Frmd.	
28.	6	2	Kl. 1.43 Eftmd.	over 0 0	2	Kl. 7.54 Frmd.	
29.	6	5	Kl. 2.49 Eftmd.	under 0	1	Kl. 8.45 Frmd.	
30.	6	7	Kl. 3.40 Eftmd.	under 0 0	6	Kl. 9.36 Frmd.	
31.	6	7	Kl. 4.30 Eftmd.	under 0 0	11	Kl. 10.26 Frmd.	
Aug. 1.	6	9	Kl. 5.20 Eftmd.	under 0 1	0	Kl. 11.13 Frmd.	
2.	6	10	Kl. 6. 4 Eftmd.	under 0 1	2	Kl. 11.59 Frmd.	
3.	6	11	Kl. 6.54 Frmd	under 0 1	4	Kl. 12.43 Eftmd.	

TABLE (continued).

Datum.	Höivande.		Klokkeslet Formiddag eller Eftermiddag.	Lavvande.		Klokkeslet Formiddag eller Eftermiddag.	Anmærkninger.
	Fod.	Tommer.		Fod.	Tommer.		
			Kl. 7.48	under 0		Kl. 1.26	
1864. Aug. 4.	6	11	Frmd.	1	4	Eftmd.	
			Kl. 8. 2	under 0		Kl. 2. 7	
5.	6	9	Frmd.	1	2	Eftmd	
			Kl. 8.45	under 0		Kl. 2.49	
6.	6	7	Frmd.	0	10	Eftmd.	
			Kl. 9.30	under 0		Kl. 3.31	
7.	6	1	Frmd.	0	5	Eftmd.	
			Kl. 10.10	under 0		Kl. 4.15	
8.	5	10	Frmd.	0	2	Eftmd.	
			Kl. 10.50	over 0		Kl. 5. 0	
9.	5	8	Frmd.	0	1	Eftmd.	
			Kl. 11.40	over 0		Kl. 5.49	
10.	5	7	Frmd.	0	2	Eftmd.	
			Kl. 12.45	over 0		Kl. 6.40	
11.	5	4	Eftmd.	0	3	Frmd.	
			Kl. 1.36	over 0		Kl. 7.34	
12.	5	3	Eftmd.	0	4	Frmd.	
			Kl. 2.31	over 0		Kl. 8.28	
13.	5	6	Eftmd.	0	3	Frmd.	
			Kl. 3.34	under 0		Kl. 9.30	
14.	6	4	Eftmd.	0	1	Frmd.	
			Kl. 4.33	under 0		Kl. 10.29	
15.	7	0	Eftmd.	0	4	Frmd.	
			Kl. 5.30	under 0		Kl. 11.27	
16.	7	9	Eftmd.	0	9	Frmd.	
			Kl. 6.19	under 0		Kl. 12.24	
17.	6	2	Frmd.	1	3	Eftmd.	
			Kl. 6.30	under 0		Kl. 1.25	
18.	6	9	Frmd.	2	0	Eftmd.	
			Kl. 7.15	under 0		Kl. 1.30	
19.	7	1	Frmd.	2	6	Eftmd.	
			Kl. 8.10	under 0		Kl. 2.15	
20.	7	1	Frmd.	2	5	Eftmd.	
			Kl. 9. 4	under 0		Kl. 3. 9	
21.	6	9	Frmd.	2	0	Eftmd.	

Efter Œnske bemærkes umgang for Alle, at Floden og Ebben löber fra Syd til Nord.

Frederiksdal, den 22de August 1864. M. A. ASBOE, Missionær.

APPENDIX to Part II. *On the Semidiurnal Tides of Port Leopold, North Somerset.*

An error has occurred in my account of the Semidiurnal Tides of Port Leopold, Transactions of the Royal Society, vol. cliii. p. 256, which I am desirous to correct.

In Table I., the last column is headed "Moon's Hour-Angle," whereas it ought to be "Moon's Hour-Angle East of Sun." In copying the Table from my note-book this error occurred, and has led to some inaccuracies in the subsequent part of my paper which ought to be corrected.

The Moon's Hour-Angle, which should be used in the calculations, is found by subtracting the means of the second and fourth columns. Thus

$$\left.\begin{array}{r}\text{Mean Hour-Angle of Moon at time of}\\ \text{Maximum Spring Tide Ranges . .}\end{array}\right\}=1^{\mathrm{h}}\ 4^{\mathrm{m}}-2^{\mathrm{h}}\ 2^{\mathrm{m}}=-0^{\mathrm{h}}\ 58^{\mathrm{m}}.$$

The same error occurs in Table II. p. 257; and its correction is similar, viz.,

$$\left.\begin{array}{r}\text{Mean Hour-Angle of Moon at time of}\\ \text{Minimum Neap Tide Ranges . .}\end{array}\right\}=6^{\mathrm{h}}\ 50^{\mathrm{m}}-7^{\mathrm{h}}\ 48^{\mathrm{m}}=-0^{\mathrm{h}}\ 58^{\mathrm{m}}.$$

This is the value of the Lunitidal interval (found without calculation), which may be safely used in the subsequent calculations. The corresponding value of the Solitidal interval is found by taking the means of the second columns of Tables I. and II., and is found to be $+0^{\mathrm{h}}\ 57^{\mathrm{m}}$, a quantity differing little from that found by calculation in p. 259, viz. $+0^{\mathrm{h}}\ 56^{\mathrm{m}}\ 20^{\mathrm{s}}$.

The Lunar Semidiurnal Tide, cleared of parallax, is

$$2M\cos^2\bar{\mu}\cos 2(m-i_m);$$

and its maximum and minimum ranges are (p. 260) 4·62 ft. and 4·23 ft.

The minimum is attained at Solstitial Springs and Equinoctial Neaps, which, from Tables I. and II., are

	d	h	m		°	′	
June	21	0	30	Moon's declination	18	51	N.
April	1	7	0	Moon's declination	16	33	N.
				Mean . .	17	42;	

and the maximum is attained at Solstitial Neaps and Equinoctial Springs, which, from Tables I. and II., are

	d	h	m		°	′	
June	29	8	0	Moon's declination	9	2	N.
March	26	1	30	Moon's declination	8	24	N.
				Mean . .	8	43	

Using these values in the expression for the Lunar Semidiurnal Tide (assuming $m=i_m$), we find

$$2M=4{\cdot}23\times\cos^2(17^\circ\ 42'),$$
$$2M=4{\cdot}62\times\cos^2(8^\circ\ 43');$$

from which we find

$$2M=4{\cdot}66$$
$$2M=4{\cdot}72$$
$$\text{Mean}=\overline{4{\cdot}69}\text{ ft.}$$

This value of 2M, the lunar coefficient, should be substituted for that found in p. 260, viz. 4·309 ft., and used in the subsequent calculations of pp. 261, 262. The corrected results stand thus:—

1. Value of $\frac{S}{M}=0{\cdot}3635$.
2. Mass of Moon$=\frac{1}{65{\cdot}35}$.
3. Mean depth of sea from Heights$=9{\cdot}84$ miles.
4. Mean depth of sea from Times $=2{\cdot}71$ miles.

XXIII. *On Uniform Rotation.* *By* C. W. Siemens, *F.R.S.*, *Mem. Inst. C.E.*

Received March 10,—Read April 12, 1866.

Amongst the means at our disposal for obtaining uniform rotation, there is none for which the same degree of accuracy can be claimed as that which distinguishes the vibrating pendulum, or the oscillating spring-wheel of the common watch; yet there are many purposes, both in physical science and in the mechanical arts, for which smaller subdivisions of time than the period of one oscillation are matter of considerable importance, and which can only be measured by uniform rotation.

Conical Pendulum.—The apparatus by which continuous rotation of the greatest regularity has hitherto been obtained, is the conical pendulum, which was first applied by James Watt to regulate the speed of his engines, and which has since received further development in the instrument known as the Chronometric Governor.

On examining into the principle involved in the conical pendulum, it will be found that the time t of its rotation is dependent upon its length l, and on the angle α which it makes with its vertical axis of rotation, which dependence is expressed by the formula

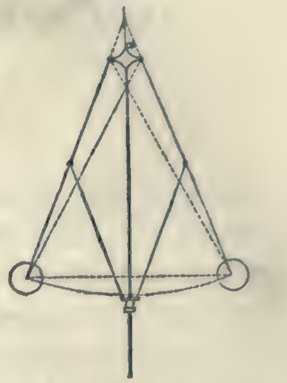
$$t=\varphi\sqrt{l\cos\alpha},$$

the coefficient φ being a function due to gravitation. The value of t being dependent upon α, it follows that "*uniform rotation of a conical pendulum cannot be obtained except on condition that the angle of its rotation remains constant.*"

Watt's *Governor.*—In the case of Watt's centrifugal governor, the angle of rotation of the pendulum varies with every change in the relative condition of power and load on the engine, and the change of angle is, indeed, taken advantage of to close or open the steam-supply valve. In order to close the steam- (or throttle-) valve the angle of rotation has to be increased, which necessitates a corresponding increase of the engine's velocity; on the other hand, an increase of the valve-orifice cannot be effected without a reduction of the speed of the engine taking place.

Considering this dependence of the action of the instrument upon permanent change of speed of the engine, the name of "governor" seems inappropriate, the instrument being, in fact, only a "moderator" of the amount of fluctuation to which the engine would be subjected without its agency. The amount of these fluctuations depends, in a great measure, upon the mechanical construction of the instrument, which is, generally speaking, very objectionable, inasmuch as the pendulous arms are mostly suspended at points beside the common axis of rotation, giving rise to an increased variation of time for a given change of angle; the reason being that the true pendulous length has to be measured from the point of intersection of the pendulums or rods with the axis of rotation, which point descends as the angle increases, causing the pendulous length to diminish at both extremities. A better result would be obtained if each pendulous rod were suspended from the point past the axis of rotation (as shown by dotted lines in fig. 1), causing the two rods to cross in the line of the axis at a point which would rise with increase of angle, and render the true pendulous length approximately uniform between certain limits.

Fig. 1.

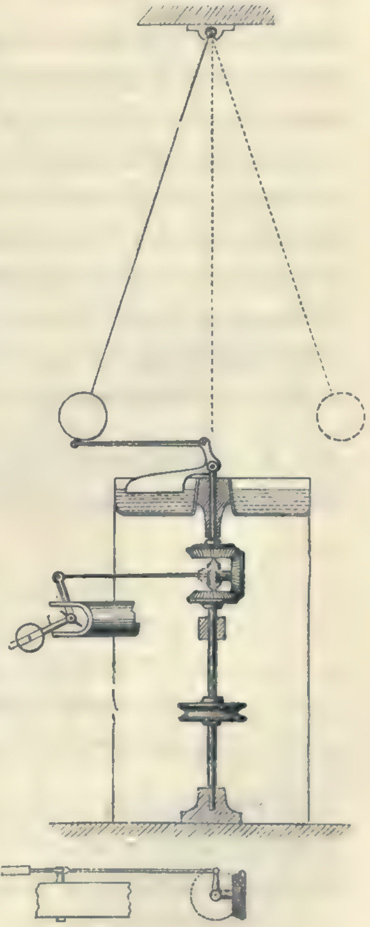


The governor of Watt is, however, subject to another defect which does not admit of an easy rectification, and which consists in its want of power to operate on the steam-valve at the moment when the equilibrium between the power and load on the engine is disturbed. It will be seen that while the engine proceeds uniformly, gravitation and centrifugal force must be in equilibrium as regards the governor-balls, but at the moment when, for instance, a portion of the load on the engine is removed, steam-power will be set at liberty for accelerating the fly-wheel. This acceleration proceeds in accordance with the well-known gravitation laws until the increase of centrifugal force imparted to the governor-balls suffices to overcome the friction of the valve and its mechanical connexions, which are not inconsiderable. In the mean time the speed of the engine will have been increased to an extent considerably beyond what is required in order to maintain the valve in its new adjustment; the action of the governor, when it does take place, will therefore be excessive, and a series of fluctuations in the speed of the engine must follow before the proper readjustment of its valve can be effected.

Chronometric Governor.—Impressed with these imperfections in Watt's centrifugal governor, I proposed, twenty-three years ago, in connexion with my brother, Werner Siemens, a governor based also on the conical pendulum, which in this case was to be independent in its action of change in its angular rotation, and, moreover, was to be provided always with a store of power ready to overcome the resistance of the valve at the first moment when the balance between the power and load of the engine was disturbed. This instrument (the chronometric governor) has been applied with success in many cases where engines were required to work with great regularity under varying conditions of load; it has also received an interesting application by the Astronomer Royal for regulating astronomical and chronographical instruments, proving the high degree of precision of which it is capable.

The leading idea involved in this governor consisted in providing a conical pendulum in *uniform rotation*, and in establishing a *differential motion* between it and the wheel driven by the engine, which differential motion was made to act upon the source of power of the latter. If this idea could be carried out, it was evident that the engine, or machine to be governed, must suit its motion closely to that of the independent rotating pendulum, because the least retardation on its part must immediately result in an enlargement of the valve-orifice (it being understood that an increase of available power is always obtainable), and the least motion in advance of the pendulum must automatically reduce the source of power. This action would be effected instantly, notwithstanding a considerable resistance in the valve, because the weight of the pendulum in rotation represents, in this case, a store of power, inasmuch as its angular velocity would have to be suddenly checked or increased as the case may be, unless the valve obeyed the first appearance of a differential motion. In order to realize these conditions, it was necessary to maintain the conical pendulum in question at a uniform angle of rotation, notwithstanding the changes of driving- or sustaining-power which must necessarily arise through its action upon the regulating valve of the engine; and this could only be accomplished by providing the means of destroying or absorbing any excess of driving-power beyond what was necessary to overcome the friction of the instrument, and which must tend otherwise to increase its angle of rotation. On the other hand, a surplus of driving-power had to be provided to prevent an occasional collapse of the pendulum in opening the valve. The sustaining- or driving-power of the pendulum was obtained in taking advantage of the differential motion, a weight being attached to a horizontal lever upon the throttle-valve spindle, which, in exerting a pressure of the differential wheel against the two principal wheels, caused an impulse to be given to the one connected with the pendulum, whereas the third wheel was driven by the engine in the direction proper to raise the weight continually. The excess of driving-power imparted to the pendulum was destroyed by calling into action a friction between two solid substances at the moment when the angle of rotation had reached its intended maximum; or a liquid resistance was introduced, such as a fan, rotating with the pendulum, being dipped into a bath of mercury or other liquid, at the moment when the extension of the pendulum was attained (see fig. 2).

Fig. 2.



The governors constructed on this principle are remarkable for their instantaneous action upon the supply-valve of the engine, when a sudden disturbance of the balance between load and power takes place; and they possess also, to the fullest extent, the power of maintaining the regulated machine at the same speed, when the load reaches its maximum, as when it is at its minimum. In the hands of the Astronomer Royal the uniformity of motion obtained by the use of this governor approaches indeed that of an ordinary chronometer, yet it is not free from objections resulting from the delicate adjustment and frequent attention requisite to maintain it in good working condition. In its application to the regulating of physical apparatus it has, moreover, been found that the conical pendulum is apt to fall into elliptical rotation, whereby the subdivisions of time below the half second become inaccurate.

FOUCAULT'S *Governor.*—Monsieur FOUCAULT, of Paris, has treated the same question in a different manner, substituting for the friction between solids, or of solids against fluids which we employed to fix the angle of rotation of the conical pendulum, the varying resistance of an air-propeller, according to the amount of area for the escape of air, which area he regulates by means of the angular elevation of his conical pendulum. The conical pendulum he employs is mounted in the manner of a WATT'S governor of the best construction, which renders his apparatus portable, and therefore convenient for general purposes, while, on the other hand, it appears to depend for its correct action upon the perfect condition of many mechanical details.

Some months since an idea suggested itself to me which, while it furnishes the elements of a very general and complete solution of the problem under consideration, appears to possess also a separate scientific interest, which chiefly induces me to bring the subject before the Royal Society.

Liquid in rotation.—If an open cylindrical glass vessel or tumbler containing some liquid be made to rotate upon its vertical axis, the liquid will be observed to rise from the centre towards the sides to a height depending on the angular velocity and the diameter of the vessel. As soon as the velocity has reached a certain limit, the liquid will commence to overflow the upper edge of the vessel, being thrown from it in the form of a fluid sheet in a tangential direction. If the velocity remain constant from this moment, the overflow of the liquid will be observed to cease, although the liquid remaining in the vessel will continue to touch the extreme edge or brim. Supposing that the velocity of the vessel be now diminished, the liquid will be observed to sink, but will rise again immediately to its former position when the rotation returns to its previous limit of angular velocity. This velocity is the result of the balance of two forces acting on the liquid particles, namely, gravity and centrifugal force.

It is a well-known fact that the curvilinear surface produced by a liquid in rotation is that of a paraboloid, the parameter of which is expressed by $\frac{g}{w^2}$, and the curve itself therefore by the formula

$$y^2=\frac{2g}{w^2}x, \quad \dots\dots\dots\dots \quad \text{(I.)}$$

x signifying vertical distance from the apex,
y the corresponding horizontal distance from the axis of rotation,
w the angular velocity of rotation, and
g acceleration by gravity in one second.

In this formula there is no factor denoting the density of the liquid, which proves that the point to which the liquid is raised by a given angular velocity is independent of the specific gravity of the liquid employed.

By substituting for y the radius r of the rotating cup at the brim, and for x the height

h of the brim above the lowest level of the liquid, we may write the foregoing general formulæ as follows,

$$h=\frac{r^2w^2}{2g}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(II.)}$$

and

$$w=\frac{\sqrt{2gh}}{r}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

two convenient formulæ for determining the height to which liquid will rise when the diameter of the rotating vessel and its angular velocity are given, or for determining the angular velocity due to a given height and diameter, it being understood that the values of g, r and h must be expressed in the same unit of length.

If it is desired to determine the number of revolutions per second n, instead of the angular velocity w, we may put

$$n=\frac{w}{2\pi},$$

and in putting this value for w $(=2\pi n)$ into the last formula, we have

$$n=\frac{\sqrt{2gh}}{2r\pi}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(IV.)}$$

These formulæ are applicable to vessels of every possible external form rotating upon their vertical axis, and to every possible liquid, but they are based upon the supposition that the liquid is raised by rotation to the upper edge or brim of the vessel, a condition which it may appear at first sight difficult to realize for practical purposes.

If the production of uniform rotation be the object in view, it is necessary that the liquid in the rotating vessel should always be at the point of overflow, although the driving-power might vary considerably, and that all surplus driving-power should be absorbed by other work than that of accelerating the rotating vessel, also that the stock of liquid within the vessel should never diminish. I hope to prove by the following demonstration that these various conditions can be fulfilled by suitable mechanical arrangements resulting in the construction of a simple and efficient instrument, which is is represented on Plate XXIX., and which has survived the ordeal of experimental proof.

Liquid Gyrometer.—The rotating vessel consists, in this case, of a cup C (Plate XXIX. fig. 1) open both at the top and bottom, but widest at the top, the sides being made to close in towards the bottom in a parabolic curve analogous to that formed by the liquid in rotation. This cup contains upon its inner surface three or four radial ribs which unite in a central boss, by which the cup is supported upon the spindle S. This support is not an absolute one, but the spindle is armed with a screw-thread of rapidly ascending path, into which the screw-threads upon the inner surface of the boss are made to fit; a fixed connexion between the driving-spindle and the cup C is established by means of a spiral spring E, one end of which is fastened to the projecting end of the spindle S, and the other to the cup. Before this spring is fixed, it is drawn out longitudinally to such an extent as to balance the weight of the cup, which latter may therefore be said to float upon the screw-threads without exercising any pressure upon the same. The upper support of the spindle S is a boss projecting from the bottom of a cylindrical vessel B of glass sides and glass-domed top, which completely encloses the cup C, while it renders its action visible: this outer vessel is filled with liquid to such a height as to submerge the lower edge of the cup. Rotation of the liquid in the outer vessel is prevented by radial ribs upon its bottom surface; and upon the external surface of the rotating cup C two concentric projections are provided, one at the upper edge, and the second near the surface of the outer liquid, for the purpose of throwing off some liquid which would otherwise be apt to adhere to the external surface of the cup, in defiance of centrifugal force, and interfere slightly with its proper action.

Rotation being imparted to the shaft S and the cup C by clockwork or from any other source, the liquid at the bottom of the cup will be acted upon by centrifugal force and rise upon its inner sides, while additional liquid will enter from without and maintain the apex of the liquid curve nearly on a level with the surrounding lake. At the moment when the liquid in rotation touches the upper edge of the cup, the speed should be such as is determined by the formula

$$n=\frac{\sqrt{2gh}}{2r\pi},$$

in which h may be taken for the height of the brim of the cup above the lake surface; but considering that the power necessary to maintain the cup at its velocity, after the liquid has been raised to its upper edge, is exceedingly small, because no fresh material has to be put into motion, it would be practically impossible to prevent further acceleration. In order to make sure that the liquid will not fall below the brim of the rotating cup, an excess of driving-power must be applied, and that excess must be disposed of otherwise than in producing further acceleration of the cup. This is accomplished by means of a continual overflow of a thin sheet of liquid, which is projected against the sides of the outer vessel and falls back into the lake at the bottom, whence a similar quantity of liquid penetrates into the cup, to be also raised by its rotation and projected over its edge.

The power absorbed in raising and projecting the liquid must be strictly proportionate to the quantity of liquid so acted on in a given time, or to the thickness of overflow, provided the condition of uniform velocity be realized; but the velocity of the cup depends upon the height to which the liquid has to be raised, and must therefore be increased in order to raise the liquid column above the brim of the cup. The necessary increase of velocity to produce such an overflow is not great, considering that the height of the liquid column increases in the square ratio of the velocity, and may be neglected in all cases where only approximate results are required, or where variations in the driving-power are comparatively small; but no high degree of accuracy could have been claimed for this instrument unless the following compensating action had suggested itself:—

Automatic Dip of Cup.—We have assumed hitherto a rigid connexion between the cup and its driving-spindle, and unless the cup does overflow, we are, indeed, justified in this assumption, the spring E being too rigid to yield to the resistance of the cup in motion when no work is performed. With an increase of power the resistance of the cup also increases, and an overflow of liquid proportionate to the power is produced; the connecting spring E must yield, at the same time, proportionately to the torsional resistance thus created, and in the same ratio the cup will descend upon the helical surface which serves for its guide. While, therefore, on the one hand, the h of our formula increases with the overflow, it is diminished, in the same ratio, by the descent of the cup, both depending directly upon the driving-power. When the stiffness and length of the spring are so adjusted that the one action equals the other for any given increase of power, it must equal it also for other amounts of increase within reasonable limits, and *strictly uniform rotation must be the result.* The "reasonable limits" to this automatic adjustment are imposed by the restricted orifice through which the liquid has to penetrate into the cup, and also by the range of action of the spring, for which the law of MARIOTTE is applicable. Experiments, to be hereafter described, have shown that the driving-power may be varied between wide limits without producing any sensible variation of speed. The final adjustment of the instrument to the normal velocity required is moreover easily effected by raising or lowering the cup while it is running, for which purpose the lower end of the upright spindle S is supported in the axis of an adjusting screw E, as will be seen by inspection of Plate XXIX. fig. 1.

Range of power increased.—The range of power through which uniform rotation can be obtained, may be further increased by an arrangement which is represented in Plate XXIX. figs. 2 and 6, and which consists in arresting the liquid projected over the edge of the cup by a belt of fixed vanes M, whence it drops through the zone of rotating radial vanes L, which again impart tangential motion to it at the expense of the superfluous driving-power of the cup of which they form part. It is hardly necessary to add that these fixed and rotating vanes only *increase the range of power of the instrument, without in any way affecting its rate of rotation*, and that a second set of fixed and rotating vanes might be added with the same effect as the first. Although the rotating cup represented in Plate XXIX. figs. 2 and 6, is not provided with the automatic dip, it is equally evident that the fixed and moveable vanes do not preclude that arrangement, which is only dispensed with in such cases where great uniformity of motion is not required.

An interesting application of such a "Liquid Gyrometer," as this instrument may appropriately be called, would be that of obtaining synchronous motion at different places connected by a telegraphic wire, for philosophical or telegraphic purposes; but in order to test its fitness for such purposes, I have constructed a clock of which it constitutes the regulating principle, the moving power being obtained by electro-magnetism.

Clock regulated by liquid in rotation.—This clock is represented by Plate XXX. figs. 7 & 8, and consists of three principal parts:—

1. The pedestal containing a battery of two "MARIE DAVY's elements" suitably arranged.

2. The body of the clock, with sides formed of plate glass, containing an electromagnet, by which rotatory motion is imparted to an iron bar or keeper fixed upon the vertical main axis which passes into

3, the regulating chamber, consisting of a close cylindrical glass vessel with domed glass top containing the rotating cup and a certain quantity of paraffin oil, which fluid is particularly applicable on account of its perfect fluidity and non-affinity for the materials composing the regulator.

The regulating cup is in this instance formed of vulcanite, and is suspended from the top of the vertical axis by means of a spiral spring, which, being fixed at both ends, not only supports the weight of the cup but acts also as a torsional spring, enabling the cup to descend upon its helical central guide whenever an increase of driving-power calls into existence its equivalent of torsional resistance.

The rings of stationary and rotating vanes are dispensed with in this instance, because no great variations in the driving-power are contemplated. The electromagnet acts by attraction of the armature during a small portion of its rotation, and one contact only is required, which is so arranged that no destruction of the metallic surfaces can arise through the discharge of extra-current sparks, which latter are received by an elastic point of platinum slightly in advance of the proper contact surface and moved by the same excentric. By this simple arrangement the usual difficulty attending dry contacts is avoided, and a continued action of the instrument ensured. A train of reducing wheels communicates the motion of the cup-spindle to hands upon the face of the clock, which record hours and minutes in the usual manner.

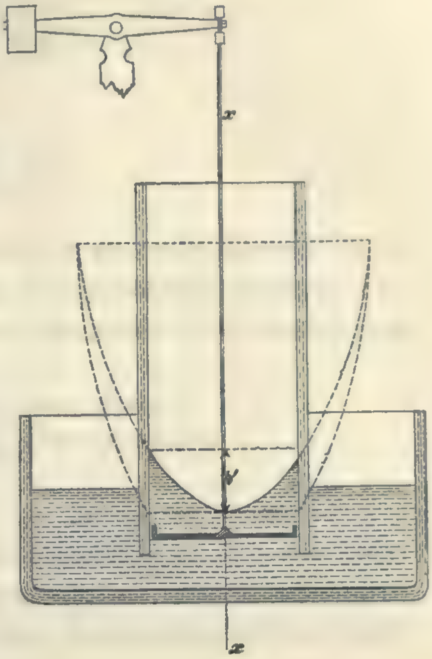
The diameter of the rotating cup being $=0{\cdot}040$ metre, and the height of its edge over the surface of the liquid $=0{\cdot}034$ metre, the number n of its rotations per second in accordance with our formula

$$n=\frac{\sqrt{19{\cdot}6\text{ metre}\times{\cdot}038\text{ metre}}}{{\cdot}040\text{ metre }\pi}=6{\cdot}9\text{ revolutions per second.}$$

Experiment gave, on the contrary, a speed of 7·5 revolutions per second, or ·6 revolution per second more than was indicated by theory, a result which seemed to stamp the action of the instrument with uncertainty, when it was recollected that no allowance had been made for the aperture at the bottom of the cup, leaving a portion of the rotating liquid without an external support.

Correction for lower orifice of Cup.—If we assume, for instance, that the sides of the cup were cylindrical and merely descended below the surface of the liquid without closing in at the bottom, we should find that by rotation of this cylinder, supposing the inner surface to be rough or armed with radial projections, the liquid would rise on the circumference above the external level of surface, but would also form a depression or vortex in the centre of rotation. The surface of the rotating liquid would be that produced by the rotation of a vertical parabola, as represented in the accompanying diagram. In order to maintain the hydrostatic equilibrium between the rotating column and the external liquid, it is necessary that its mean height of column should remain the same, or that the plane of external liquid level should divide the solid figure comprised between the cylinder and the curve of rotation into equal parts. In order to realize these conditions experimentally, it would be necessary to provide the lower portion of the rotating cylinder with an easy fitting and balanced piston, without which circular currents would be produced within the rotating liquid (descending by force of gravity at the sides, and rising again in the centre) and mar the result.

Fig. 3.



The body comprised between a paraboloid of the height h' and a cylinder is, however, divided equally by a horizontal plane cutting it at the distance of $\frac{h'}{\sqrt{2}}$ from the edge, or at

$$h'-\frac{h'}{\sqrt{2}}=\cdot293h'$$

from the apex. The form of the curve depends upon the angular velocity alone, and would remain the same if the upper diameter of the tube were to be increased, only the curve would in that case have to be continued until it met the sides (as shown by dotted lines), and to the extent of these prolongations the liquid would be raised higher above the external level without producing a corresponding depression in the centre of rotation.

It follows that the aperture at the bottom of the rotating cup causes a vortex or depression of the apex of the curve of rotation below the external liquid to the extent of ·293 part of the height due to its own diameter, and to the correct number of rotations n' per second.

Now

$$n'=\frac{\sqrt{2g(h+\cdot293h')}}{2r\pi},$$

and also

$$n'=\frac{\sqrt{2gh'}}{2\varrho\pi}$$

if ϱ is the radius of lower aperture of cup; therefore

$$\frac{\sqrt{2g(h+\cdot293h')}}{2r\pi}=\frac{\sqrt{2gh'}}{2\varrho\pi},$$

or

$$h'=h\frac{\varrho^2}{r^2-\cdot293\varrho^2};$$

and in substituting this value for h' in the first formula, we have

$$n'=\frac{\sqrt{2gh+2gh\frac{\varrho^2}{r^2-{\cdot}293\varrho^2}}}{2r\pi},$$

or

$$n'=\frac{\sqrt{2gh\left(1+\frac{\varrho^2}{r^2\times{\cdot}293\varrho^2}\right)}}{2r\pi}, \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \text{(V.)}$$

for our *corrected formula to determine the velocity of cup with continuous overflow.*

In applying this formula to the clock, taking for ϱ its value of 8 millims. and the other values also in millimetres in order to avoid fractions, we find

$$n'=\frac{19600\times38\left(1+\frac{64}{400-16{\cdot}05}\right)}{40\pi}=7{\cdot}4 \text{ revolutions per second,}$$

or ·1 revolution per second less than the actual speed. This remaining excess of the *actual* over the *calculated* velocity of the cup is rather more than what may be fairly attributed to error of measurements, and appears to be due to adhesion of a film of liquid (which may be estimated at nearly ·25 millimetre thickness) to the inner sides and edge of the cup, whereby its *effectual* dimensions are proportionately reduced. For a uniform speed this error must be a constant quantity, which cannot affect the working of the instrument injuriously, so long as the other conditions are such as to produce uniform rotation. The discrepancy is diminished by increasing the dimensions of the cup, and its amount is such that the compensation is effected, under all circumstances, by one or two turns of the regulating screw supporting the vertical spindle.

When the regulation of the cup is once effected, it continues to rotate at a remarkably uniform rate. Change of temperature affects the density of the liquid considerably, but does not influence the rate of the cup otherwise than inasmuch as it affects the level in the cup-chamber, rising with increase of temperature proportionately to the depth of liquid it contains, which change is inconsiderable. The lineal dimensions of the cup, and the length of the suspending spring, will also increase, all tending to lower the rate with increase of temperature; but, on the other hand, the length of the upright cup-spindle increases with increase of temperature, and by regulating the length and composition of that spindle properly, entire compensation for change of temperature is effected. The cup-chamber being entirely closed against the atmosphere, no fault can arise through evaporation or dispersion of the liquid within moderate periods of time.

In the case of the clock under consideration, no compensation for change of temperature was provided, nor is the cup entirely balanced by the spring, yet its rate is as uniform as that of the common clock with which it has been compared; but in order to test the regulating-power of the instrument, the driving-power was varied by the introduction of artificial resistances into the galvanic circuit, when the following results were observed:—

Time of common clock, in seconds.	Mercury units of resistance of clock and battery.	Units of resistance put into circuit.	Relative value of driving-power.	Time of liquid gyrometer clock, in seconds.	Variations in time produced, in seconds.
720	110	0	100	736	16 slow
720	110	10	92	734	14 ,,
720	110	20	85	734	14 ,,
720	110	30	78	733	13 ,,
720	110	40	73	732	12 ,,
720	110	50	69	731	11 ,,
720	110	60	64	729	9 ,,
720	110	70	61	726	6 ,,
720	110	80	58	723	3 ,,
720	110	90	55	720	correct
720	110	100	52	723	3 fast
720	110	110	50	726	6 ,,
720	110	120	48	725	5 ,,
720	110	130	46	724	4 ,,
720	110	140	44	722	2 ,,
720	110	150	42	729	9 slow
when the overflow had ceased					

This result shows that the spring employed was decidedly too weak, producing a *decrease of speed* with *increase of power*.

A more careful adjustment of the spring would improve these results, which suffice, however, to prove the capabilities of the instrument.

It appears at first sight as though the friction of the cup upon the threads of the screw must interfere with its automatic adjustment; but this is practically not the case, owing to the circumstance that small fluctuations in the resistance continually occur, causing torsional oscillations of the cup, the mean of which must be its true position notwithstanding friction, which friction moreover is reduced to a minimum, owing to the suspension of the weight by the spring.

Another interesting quality of the gyrometric cup is its comparative indifference to a vertical position; it may, indeed, be tipped very considerably without interfering with the uniform overflow all round, and the time of its rotations is diminished only in the ratio of the square roots of the vertical mean heights, or it is

$$n':n=\sqrt{h}:\sqrt{h\cos\beta},$$

or for a tipping angle $\beta=3°$,

$$n':n=1:1{\cdot}0007,$$

showing that no particular care is requisite to place the instrument upon a horizontal foundation.

Gyrometric Governor.—The most useful practical application of this instrument is that of regulating the power and velocity of steam-engines. A cup of very large dimensions, provided with several belts of check-vanes and with the automatic dip arrangement, might be conceived which, being connected by gearing with the main shaft of an engine, would limit its velocity by absorbing directly all its surplus power. This surplus power would appear in the cup-chamber in the form of molecular motion or heat, and would have to be got rid of by the application of cooling agents, if the natural dispersion of heat by radiation would no longer suffice to keep down the temperature. This would, however, be a wasteful proceeding, and it becomes necessary to operate, not upon the power produced, but rather upon the source of power, by rendering it always equal to the accidental resistance or load in order to maintain uniform velocity. The arrangement adapted for this purpose is represented by Plate XXIX. figs. 2, 3, 4, 5 & 6.

S is the main shaft of the engine, which imparts motion to the upright spindle H carrying an inverted wheel E. The axis A of the regulating cup, being concentric with the spindle H, carries a pinion F, and both the wheel and the pinion gear into two intermediate or planet-wheels G and G′, which latter are loose upon studs and are suspended from a rocking-frame I, the latter being free to turn upon its central support. The rocking-frame I is connected by a rod R to a bell-crank lever O, which is fastened upon the spindle of the steam-regulating or throttle-valve V; but the horizontal arm of the lever O carries a weight P which, being acted upon by gravity, tends to open the valve and at the same time to force the rocking-frame I, with its planet-wheels G and G′, round the vertical axis. This pressure is resisted, on the one hand, by the teeth of the pinion F, which can only yield in the ratio imposed by the rotating cup C, and on the other hand, by the teeth of the inverted wheel E, which latter, being driven round by the engine in the direction contrary to the effort produced by the weight P, causes the latter to be continually raised. If the engine should succeed in raising the weight P, say 100 millims., while the regulating cup yields also to the extent of 100 millims., then the lever O, and with it the regulating valve V, will retain their relative position; but if the engine should raise it, say 95 or 105 millims., while the cup yields 100 millims., then the valve will be either opened or closed by 5 millims., and the engine will be urged or checked, as the case may be, to such an extent as to make its revolutions coincide again absolutely with those of the regulating cup.

The driving-power of the cup is limited by the weight P, and may be considered as a constant regulated quantity (although it is derived indirectly from the engine); but whenever the valve has to be opened or closed, a resistance arises which goes either in diminution of or in addition to the weight P, and the power of the cup must be such that its speed remains sufficiently uniform under the influence of these occasional variations.

By means of the automatic dip arrangement it would not be difficult to obtain perfect uniformity, notwithstanding these irregularities in the driving-power; but in the case of steam-engine governors this arrangement is dispensed with for the sake of a more immediate action upon the valve at the moment when a differential velocity arises. Supposing that the greatest amount of occasional variation of speed is to be 1 per cent., and that the dimensions of the cup are as follows,

Diameter at upper rim . . . . =200 millims.
Diameter of rim above the liquid . . . . =200 millims.
Diameter of orifice at bottom of cup . . . . . = 90 millims.

we find the available power of the instrument in the following manner:—

The normal speed of a cup of these dimensions is, according to our formula,

$$n=\frac{\sqrt{19600\times 200\left(1+\frac{45^2}{100^2-\cdot 293\times 45^2}\right)}}{200\pi}=3\cdot 31 \text{ revolutions per second.}$$

The height to which the liquid is raised by rotation increases in the square ratio of the speed of rotation, the increase of height due to 1 per cent. increase of speed would therefore result from the following proportion,

$$100\,v : 101\,v=\sqrt{h} : \sqrt{h'},$$

or the height due to the increased speed,

$$h'=204 \text{ millims.},$$

that is to say, the liquid would be raised 4 millims. above the brim of the cup, which, being an unbalanced column, will produce an upward flow of the liquid in the cup, as expressed by the well-known formula,

$$v=\sqrt{2gh};$$

or h being in this case $=4$ millims., we have

$$v=\cdot 280 \text{ metre flow per second,}$$

which, if multiplied by the least sectional area at the entrance into the cup $=\cdot 0057$ square metre, gives the quantity of liquid

$$\cdot 280 \text{ metre}\times\cdot 0057 \text{ square metre}=\cdot 0016 \text{ cubic metre,}$$

or 1·6 litre of liquid raised 204 millims. high and projected with a velocity of

$$\tfrac{101}{100}\,3\cdot 31\times 2r\pi=2\cdot 1 \text{ metres per second}$$

over the brim of the cup, to be stopped by the stationary wings and once more accelerated by the rotating wings, which, being one-fifth more in diameter than the cup itself, impart to the liquid a velocity of

$$\tfrac{6}{5}\,2\cdot 1=2\cdot 5 \text{ metres per second.}$$

These accelerations represent a power which, according to the formula

$$h=\frac{v^2}{2g},$$

is equal to the same liquid being lifted

for $v=2\cdot 1$ metres . to ·225 metre height,
and for $v=2\cdot 5$ . . to ·320 metre height.
In the cup it was lifted to ·200 metre height,
making a total lift . . to ·745 metre height.

If the liquid employed is water, the 1·6 litre represents 1·6 kilogram., and the resistance produced by 1 per cent. increase of velocity is

$$1\cdot 6\times\cdot 745=1\cdot 2 \text{ kilogrammetres per second,}$$

which is equivalent to *forcing a valve rod or lever through one decimetre space in ten seconds against a resistance of* 120 *kilograms.*

This force exceeds by far what is usually required of a governor, and fits the new instrument for the accomplishment of objects which hitherto could not be attempted, such for instance as regulating the power of engines by the link motion or other variable expansion gear (whereby a considerable saving of fuel may be effected), or moving the gate of a water-wheel.

The most striking feature of this governor is, however, the rapidity with which a readjustment between power and load of an engine is effected; experiment has proved that *two-thirds of the total load upon an engine may be suddenly thrown off without producing any visible change in its rotation.* It must be borne in mind that the variation of 1 per cent., which was assumed in calculating the power of the instrument, applies only to the short period of ten seconds, during which the readjustment of the valve is effected, after which the cup and, with it, the engine returns to its normal rate of rotation; but an increase or decrease of speed of 1 per cent. during ten seconds is so small a total amount that it is not perceptible to the eye, and may be regarded as non-existing for practical purposes.

A uniform velocity of engines, such as is secured by this instrument, is of considerable practical importance in spinning, grinding corn, and other manufacturing operations, because it not only prevents breakages and irregularities in the quality of the work produced, but it enables manufacturers to attain to the maximum speed at which their work can be produced.

It has been shown that the rotating cup is not sensitive to tipping, a circumstance rendering the gyrometric governor also applicable to marine engines, which are much in need of a means for maintaining a uniform speed, particularly where the screw propeller is used, which, in being raised by waves above the water, allows the engine to fly off at a dangerous speed.

The gyrometric cup appears therefore to be equally applicable for maintaining powerful machinery at a nearly uniform velocity, and for obtaining the higher uniformity of rotation requisite for philosophical and telegraphic instruments.

XXIV. *Researches on the Structure, Physiology, and Development of* Antedon (Comatula, *Lamk.*) rosaceus.—Part I. *By* William B. Carpenter, *M.D., F.R.S.*

Received June 15,—Read June 15, 1865.

		Page.
I.	Introduction	671
II.	Historical Summary	673
III.	External Characters, and Habits: Synonymy	692
IV.	Structure of the Skeleton, with its Ligaments and Muscles	702
V.	Development of the Skeleton	726

I.—INTRODUCTION.

That the only secure basis of Zoological Science is afforded by a thorough elucidation of the structure and life-history of *typical forms* representing particular subdivisions of the Animal Kingdom, will not, I anticipate, be disputed by any Naturalist of the present day. And every one who is even slightly acquainted with the history of that Science must be well aware that the standard Monographs which have been devoted to this object have exerted a more permanent influence on its progress, than have any of those comprehensive Systems which have been set up from time to time, and, after lasting for a while, have been overthrown to make way for others scarcely more durable. For any System of Classification is liable to be invalidated by new discovery; and the utmost which can be claimed for it is, that it accurately represents the state of knowledge at the time of its promulgation. But every Monograph which contains a faithful description of the structure and life-history of any type whatever, however far it may be from absolute completeness, presents a body of facts which subsequent research may add to but cannot set aside; and may come to acquire, even at a long subsequent period, a value not anticipated by its author.

I cannot suppose, therefore, that any apology is needed for my offering to the Royal Society a detailed account of perhaps the most interesting of our British Echinoderms; of which the structure, notwithstanding the attention given to it by various eminent Anatomists, has been hitherto but very imperfectly made out; whilst of its life-history still less is known. That I have solved every problem which its study has presented, is far more than I can affirm; but I venture to think that what I now bring forward will stand the test of future scrutiny; and that the results I have attained will prove of importance, not merely in leading to a better understanding of the important group of which *Antedon* is a representative, but also in helping to the solution of certain fundamental questions in General Physiology.

The peculiar interest of *Antedon* as a "typical form" arises from its being the only representative now left in British seas of that wonderful Order CRINOÏDEA, which, under various modifications, has maintained its place in our Fauna from the Silurian epoch to the latest Tertiary period. It is true that in some important particulars, *Antedon* is a less characteristic representative of the Crinoïdea than is the existing *Pentacrinus* of the West Indian seas; and a complete Monograph of the structure and life-history of that organism would be one of the most valuable contributions which Palæo-zoological science could receive. But for such a Monograph there is unfortunately no reasonable ground of hope. The rarity with which specimens of this *Pentacrinus* have occurred, and the imperfection of the state in which they have been preserved, have hitherto prevented any save a very unsatisfactory account of its structure from being given; although the best of these specimens fell under the examination of an Anatomist and Physiologist no less able than Professor JOHANN MÜLLER. And even supposing that a fortunate chance should throw a perfect and well-preserved specimen in the way of some equally accomplished Naturalist, he could do no more than give a minute description of its organization;—a knowledge of its life-history being likely to remain unattainable, on account both of the rarity of the species and of the great depths at which alone it is found.

Moreover, although in its adult state *Antedon* seems to depart widely from the typical Crinoids, in having neither root nor stem, and in possessing a power of free locomotion of which they are altogether destitute, yet this departure involves what is really (in a physiological point of view) the least essential part of the Crinoidal fabric;—a part, moreover, which exists in that earlier stage of this animal's life, wherein it is in this as in all other particulars a true Crinoid; and which is afterwards replaced, so far as its function is concerned, by a prehensile apparatus that is subservient to the very same purpose. For, as I shall show hereafter, the mature *Antedon* habitually clings by its dorsal cirrhi to a fixed attachment, so as to resemble its Pentacrinoid larva in its ordinary habit; using its power of free locomotion only when persistence in its position would be no longer conformable to its requirements.

It has been, therefore, because every addition to our knowledge of *Antedon* contributes to the elucidation of the structure, physiology, and life-history of the CRINOÏDEA generally, that I have thought it worth while for some years past to devote a considerable portion of such brief periods of leisure as I have been able to command, to the careful study of the species (*A. rosaceus*) which presents itself abundantly on various parts of our northern, western, and southern shores. When I commenced this study, I entertained the hope of being able to trace out the whole history of its development, from the very commencement of its existence as a free-swimming larva. But I soon found that the earlier stages of this process take place during a part of the year in which my official duties do not allow of my visiting the coast; and learning that Professor WYVILLE THOMSON was able and willing to undertake this part of the inquiry, I gladly arranged with him that he should work out the developmental history of *Antedon* as far as the early Crinoidal stage, from which I should myself be prepared to take it up; and thus his Memoir on the Embryology of *Antedon rosaceus*, which has already appeared in the Philosophical Transactions (1865), will serve as the complement of my own.

Before proceeding, however, to detail the results of my researches, I think it right to give a somewhat particular account of what has been already done by those who have made a special study of *Antedon*; and also to mark out the principal stages in the progress of our general knowledge, both of the true character of the CRINOÏDEA as constituting one of the primary Ordinal subdivisions of the Class ECHINODERMATA, and of the relationship of the typical Crinoids to *Antedon.* It will appear in this Historical Summary (p. 682) why I have thought it right, in concurrence with the views of Dr. J. E. GRAY[1], Professor WYVILLE THOMSON[2], and the Rev. ALFRED M. NORMAN[3], to revert to the generic name *Antedon* given to this type by FRÉMINVILLE, in preference to using either the designation *Comatula* conferred upon it by LAMARCK, under which it is much more generally known, or that of *Alecto* given to it by LEACH, which is used by the Scandinavian Naturalists.

II.—HISTORICAL SUMMARY.

The earliest account of *Antedon* which I have been able to find, occurs in the 'Phytobasanus'[4] of FABIUS COLUMNA; an author who deserves to be commemorated for the excellence of his descriptions of various plants and animals, and for the fidelity and beauty of his delineations, which were engraved on copper and printed on the same page with the letter press. The figure he gives[5] of his δεκαδασυακτινοειδὴς is so characteristic as to enable me almost certainly to identify it with the species which forms the subject of the present memoir; indeed I do not think it has been since surpassed by any figure not drawn from the animal in its natural position during life. I quote the words in which this author commences his description, as indicating the remarkable abundance of the specimens that fell under his notice, and the strong impression made upon him by their beauty:—"Nova et perelegans est hujus Stellæ forma, ab aliis omnibus differens nec adhuc descripta, nostro litori frequens, ita ut nec ulla retrahantur retia, quin ipsis implicata, et simul cum piscibus in foro etiam non inveniatur." He gives a very accurate description of its jointed arms and of its dorsal cirrhi; but he fancied that the latter were used to grasp food and to draw it into the mouth, which he erroneously supposed to be át the central point from which they radiate. Of the soft visceral mass occupying the ventral cavity of the cup, and having the mouth in its centre, he says, "ex adversâ parte corpus conspicitur rotundum, læve, molle, cujus interiora propter tenuitatem considerare nequivi; ipsum verò et facillimè disjungitur a stellâ." Its colour he originally speaks of as *subrubens*; but in a later treatise[1] (Observationes, Cap. III. p. 5) he describes it as *croceum*; and he further remarks,—"reperiuntur frequenter vario colore distinctæ veluti maculosæ; partes quidem cirrorum lutescentes, aliæ albicantes, aliæ rubentes, aliæ pullo colore,"—a variety which has continually fallen under my own observation. And he further notes the remarkable fact that if these animals are placed whilst yet alive in fresh water, they impart their colour to it in a very short time.

---

[1] British Museum Catalogue of British Radiata, p. 28.

[2] *Op. cit.*

[3] "On the Genera and Species of British Echinodermata," in Annals of Natural History, 3rd ser. vol. xv. p. 99 (Feb. 1865).

[4] Φυτοβάσανος, sive Plantarum aliquot Historia. *Neapoli*, 1592.

[5] See p. 12 of the Appendix to the Phytobasanus, entitled "Piscium aliquot Plantarumque novarum Historia."

The figure and description of FABIUS COLUMNA were adopted, without the addition of any further particulars, by ALDROVANDUS in his great work 'De Animalibus Insectis' (*Bononiæ*, 1602); and from this it seems to have passed into other systematic treatises of the 17th Century.

At the end of that century, however, there occurs a very remarkable notice of this type, on the part of a naturalist who deserves more honour than he has gained; namely EDWARD LLHUYD[2], who succeeded Dr. PLOT as Head Keeper of the Ashmolean Museum.

In order rightly to appreciate its value, we must look back to the history of the ideas which had prevailed up to that time in regard to the fossil CRINOÏDEA.

The earliest author who systematically treated of Crinoidal remains was the celebrated AGRICOLA[3]; although from the manner in which he speaks of them it is evident that they had long attracted the attention of Naturalists, and that the names *Trochites*, *Entrochus*, and *Encrinus* had found their way into general use,—the first being applied to the separated joints of cylindrical stems, the second to fragments of similar stems composed of several joints, and the third to the summits, especially to that of *Encrinus liliiformis*, the species most commonly known. Of the real relationship of the three kinds of bodies thus distinguished, he does not seem to have had any idea. AGRICOLA further gave the distinctive designation *Pentacrinus* to crinoidal summits which had lost their digitations, and which showed five principal radiations; whilst he conferred that of *Astroïtes* or *Asteria* upon fragments of pentagonal stems, of which each separate joint presents some resemblance to a Starfish. The descriptions of Agricola were repeated by Conrad Gesner[1], who gave a figure of a portion of the stem of *Pentacrinus briareus* under the name of *Asteria*, and of a portion of the stem of *Encrinus liliiformis* under that of *Entrochus*; like his predecessor, moreover, approximating the Crinoids to the "lapides judæi" (fossil spines of Echini) and to Belemnites. No advance seems to have been made in the knowledge of the Crinoïdea until 1669, when Lachmund[2] for the first time figured a complete specimen of *Encrinus liliiformis* under the name *Pentagonos*, and showed that the *Entrochi* and *Trochites* were really parts of the same organism. Better figures of the summits of some palæozoic Crinoïdea were soon afterwards given by Martin Lister in his "Description of certain stones figured like plants, and by some observing men esteemed to be plants petrified"[3]: but having unfortunately adopted the erroneous notion that the Crinoids were the fossil remains of Plants which had lived at a great depth in the sea, he was led to regard the body of the Crinoid as the base of the stem, and its arms as ramifications of the roots. Two years afterwards Lister published figures of some stems of *Pentacrinus*[4], which also he regarded as representing marine plants. And not long subsequently he was followed by Beaumont[5], who described and figured some additional types of palæozoic Crinoïdea under the name of "rock-plants growing in the lead mines of Mendip Hills."

---

[1] Minus cognitarum rariorumque nostro cœlo orientium stirpium ἔκφρασις, . . . item de Aquatilibus aliisque nonnullis Animalibus libellus. *Romæ*, 1616.

[2] LLHUYD was born in Carmarthenshire in the year 1670; was a student of Jesus College, Oxford; travelled for scientific purposes throughout England, Scotland, Ireland, and Brittany; and died at the early age of thirty-nine. His merits were thoroughly appreciated by the late Professor E. FORBES, who, in dedicating to him the genus *Luidia*, thus eulogizes him:—"He was a man of great knowledge and great talent. His studies were extended over large tracts of science and literature, and he enlightened both with his researches and his writings. He united a comprehensive and philosophical mind with an observing eye, and the energy to execute. Amid the multiplicity of his studies there was no confusion. He wrote on insects, plants, fossils, antiquities, and languages; on all much and well. His principal works were 'Lithophylacii Britannici Ichnographia,' and 'Archæologia Britannica.' Ray praised him. Strange to say, his name is omitted in many of our cyclopædias, which devote whole pages to men of less repute." (British Starfishes, p. 136.)

[3] See especially Book V. of the Supplement "De Naturâ Fossilium" to his great work 'De Re Metallicâ,' first published about 1530, and many times subsequently reprinted.

It was under the influence of such misconceptions on the part of the best-informed Naturalists of the time,—as well as of the doctrine still prevalent among the less instructed, that fossils are nothing else than "curiously figured stones" deriving their peculiar shapes from some "plastic virtue latent in the earth,"—that the researches of Llhuyd upon the fossil Crinoïdea were commenced; and it is therefore very much to his credit that he should have made such an important step in advance, as not only to refer these remains to the same group with the Sea-stars, but also to fix upon that particular Sea-star which we now know under the name *Antedon*, as the type to which they are most nearly allied. As this fact has been entirely ignored by the recent historians of this department of Palæontology, MM. de Koninck and le Hon[6] (to whose labours I am indebted for several references to the authors named in this summary), I think it right to cite the evidence of it in some detail.

---

[1] De Rerum Fossilium, lapidum et gemmarum maxime, figuris et similitudinibus liber. *Tiguri*, 1565.

[2] Oryctographia Hildesheimensis, pages 58, 59.

[3] Philosophical Transactions, No. 100 (1673).

[4] "A letter containing his observations of the Astroïtes or Star-Stones," in Philosophical Transactions, No. 112 (1675).

[5] Philosophical Transactions, No. 129 (1682), and No. 150 (1683).

[6] Recherches sur les Crinoïdes du Terrain Carbonifère de la Belgique. *Bruxelles*, 1854.—The following is all the mention made by these authors of the researches of Llhuyd. "A la fin du XVIIme siècle parut l'ouvrage de Lwyd, qui, par les nombreuses figures qu'il contient et les changements que son auteur fit subir à la nomenclature de son époque, semble avoir produit une assez vive impression dans le monde savant au moment de sa publication. L'auteur y a employé divers noms pour désigner les différens fragmens de Crinoïdes qu'il a figurés, ou qui ont fait partie de sa collection. C'est ainsi qu'il donne les noms génériques de *Porpites*, d'*Entrochus*, de *Volvola*, et d'*Asteria* à des fragmens de tiges de divers espèces de Crinoïdes; qu'il désigne sous celui de *Stellaria*, de *Volvola*, de *Modiolus*, et d'*Astropodium* un certain nombre de sommets et de fragments de sommets de ces animaux. Ce dernier nom suffit pour faire comprendre que Lwyd, à l'exemple de Lister et de Beaumont, a confondu ces sommets avec leurs racines" (p. 30).

The 'Lithophylacii Britannici Ichnographia' of EDWARD LLHUYD[1] (1699) is a work which, the more it is examined, leaves a stronger and yet stronger impression of the industry and sagacity of its author. To elucidate the nature of Fossils by the comparison of their forms with those of existing Animals and Plants,—familiar as the principle now seems to us,—had not been systematically attempted (so far as I am aware) by any previous Naturalist; and no one who may bestow a little attention on the contents of the 'Lithophylacium' can fail to perceive that it is something much more valuable than a mere collector's catalogue, and deals with questions far more important than those of nomenclature. LLHUYD'S sixth class, that of *Crustacea punctulata*, includes all the fossil remains which we should now refer to the Class ECHINODERMATA; and in the general observations at the head of this division he expressly says,—"unde ad hanc classem retulimus omnes lapides ejusmodi materiâ conflatos; sive ii ad Echinos spectent, ... sive ad Stellas marinas, ut Astrorrhiza, Astropodium, Asteria, Entrochus, Volvola, Appendicula, &c." (these being the names which he assigned to various Crinoïdal fragments). Further, in the supplemental *Epistolæ* contained in the same volume, we find an express discussion on the relations of the *Encrinus* of LACHMUND, the *Entrochus* of AGRICOLA, and the *Asteria* of PLOT, to existing forms of Sea-stars, as well as of the separated parts just named to each other; and it is quite obvious that he was perfectly satisfied that these fossils were neither minerals nor plants, but stony ossicles of Sea-stars. He not only put forth this conviction with yet greater earnestness in a subsequent Memoir[2], which seems to have escaped the notice of the historians just cited, but even distinguished *Antedon* as the particular Sea-star to which the CRINOÏDEA are most nearly related. His statements on this point are so remarkable as to deserve being quoted in his own words. After describing nine specimens of different kinds of recent Starfish, he proceeds (§ XVIII.) as follows:—"Inter has decem, tum ob elegantiam, tum quod maxime rara sit, primas tenet, quæ decimo loco exhibetur, decempeda Cornubiensium; seu Stella rubra loricata, claviculato modiolo; quinis radiis constans, pennatis ab exortu bifidis. In Cornubia juxta Pensans cum antecedente reperimus, sed longinquo maris refluxu. A Stella decem radiorum COLUMNÆ, si diversa sit, parvitate præsertim distinguenda est. COLUMNA enim suæ Stellæ pedalem tribuit longitudinem, cum nostra sex aut septem uncias non exsuperet." With this *Decempeda Cornubiensium*, the *Stella Δεκάκνημος rosacea* of LINCK, our own *Antedon rosaceus*, LLHUYD afterwards (§ XXX.) compares a fossil "e fodinis Glocestrensibus," and specifies the following as the points of similarity:—"Videmus enim (1), modiolum esse utrique; (2) modiolo appendentes claviculas aut capreolos; (3) quinos radios, a primo exortu bifidos; (4) articulorum cujuslibet radii commissuram loricatam; (5) denique, radiis ab inferiori parte articulatim adnascentes aristas. *Hisce visis, Stellam decempedam lapideam, aut fossilem, hunc lapidem pronunciare, nemo, opinor, dubitabit.* (§ XXXI.) Fatemur nihilominus, quoad modiolorum figuram, multum interesse discriminis, cùm lapidea Stella quasi ansellam habeat stellatam, ubi altera scutulum; et hanc majoris esse molis marinâ. Verum hæ notæ aliam tantum speciem inferunt, genus non tollunt. Concesso itaque, hunc lapidem decempedam esse; comperimus tandem Asteriam nonnullam nihil aliud fore, quam decempedæ modiolum; quod ex hoc ipso specimine manifestum est. Dixi nonnullam, quoniam variæ dantur Asteriæ, earumque aliquot Stellarum, quas coriaceas diximus, vertebras exprimere alias docuimus, et ex No. 19, ubi Asteriæ parvæ cum Asterisci ossiculis denudatis conferuntur, propemodum constare arbitror." In the same method of careful and intelligent comparison he proceeds in subsequent sections to show that the *Encrinus* of LACHMUNDUS is similarly related to his *Decempeda*; and although he seems to have been far from comprehending the true character of the stems of the Crinoïdea (no recent pedunculate type of the group having been known to him), yet I think that no one who peruses the passages I have quoted can refuse him the credit of having—not as a mere guess, but on the sound basis of anatomical correspondence—distinctly predicated the intimate relationship between our recent *Antedon* and the fossil CRINOÏDEA; a relationship that was subsequently overlooked by Zoologists of the highest eminence, and has only within a comparatively recent period come to be generally admitted.

---

[1] The dedication of this work to MARTIN LISTER is in the following terms, alike honourable to both parties: —"Erudito imprimis viro D. MARTINO LISTER, Doctori Medico scriptis et praxi claro, Societatis Regiæ Socio illustrissimo; Musei Oxoniensis, post ipsum cujus nomen præfert nobilissimum Ashmolum, fautori primario; Bibliothecæ ibidem physicæ et antiquariæ fundatori munifico; fossilium Britanniæ insulæ indagatori primo et fœlici; præceptori suo indulgentissimo et Mecænati æternum colendo; hanc qualemcunque Lithophylacii Britannici Ichnographiam, officii et gratitudinis ergo, humillime offert ac dedicat EDVARDUS LUIDIUS."—Of the esteem in which the labours of LLHUYD were held by his contemporaries, a very interesting record is contained in the following notification:—

Hujus Libri centum et viginti tantùm Exemplaria impressa sunt, impensis infrascriptorum

ILLUSTRISS. VIRORUM,

D. Baronis *Sommers*, summi Angliæ Cancellarii.
D. Comitis de *Dorset*, &c.
D. *C. Montague*, Cancellarii Scaccarii.
D. *Isaaci Newton*.
D. *M. Lister*.
D. *T. Robinson*.
D. *H. Sloan*.
D. *Fr. Aston*.
D. *Geoffray*, Parisiensis.

[2] 'Prælectio de Stellis Marinis Oceani Britannici, nec non de Asteriarum, Entrochorum, et Encrinorum Origine,' published at Oxford in 1703, and incorporated as an Appendix in the great work of LINCKIUS, 'De Stellis Marinis' (1733), and also in an edition of the 'Lithophylacium' published in 1760.

The credit of having explicitly pointed out that the CRINOÏDEA, far from belonging to the Vegetable kingdom, are true Animals, closely approximating in structure to the existing types known as "Sea-stars," is assigned by MM. KONINCK and LE HON, as also by MM. BLAINVILLE and DUJARDIN, to ROSINUS[1]. Not only, however, was his treatise on the subject posterior by sixteen years to that of LLHUYD, but his conclusion was much less exact; his approximation of the Crinoïdea having been not to the genus

---

[1] 'Tentaminis de lithozois ac lithophytis olim marinis, jam vero subterraneis, prodromus, sive de stellis marinis quondam, nunc fossilibus disquisitio.' *Hamburgh*, 1719.

Antedon but to the genus *Euryale.* Hence it is obvious that in regard alike to Llhuyd's priority in time, and to the greater accuracy of his conclusion, we are justified in claiming for our own countryman the merit of having been the first to take up this important position.

Returning now to the history of *Antedon*, we find it characteristically described as a peculiar type of "Sea-stars" in the remarkable work of Linckius[1]; who seems to have been the first to attempt to bring together the large number of forms of this group acquired by the industry of collectors, and to endeavour to systematize them. Although his principles of classification were far from sound, and conducted him to an arrangement which was in many respects erroneous, yet they led him to erect *Antedon* (of which six species regarded by him as distinct are described under three generic names) into a group distinct not only from the *Asteriadæ*, but also from the *Ophiuridæ*, with which they have been associated by many later systematists. To this group (termed by him a Class, but rather in reality a Family) he assigned the name *Crinitæ* sive *Comatæ Stellæ*, on account of the hairy appearance given to the arms by the "capillary fibres" with which they are fringed; thus distinctly foreshadowing the name *Comatula* conferred upon this generic type by Lamarck. The first of his genera he named Δεκάκνημος, to indicate its possession of ten radiating *caudæ crinitæ*; and he ranges under it three species, (1) the *Crocea Zaffarana Neapolitanorum*, or δεκαδασυακτινοειδὴς of Fabius Columna, (2) the *Rosacea* or *Decempeda Cornubiensium* of Llhuyd, and (3) the *Barbata* or *fimbriata* of Barrelier. Of the first he quotes Columna's description without copying his figure; of the second he gives a figure, which though imperfect, is sufficient for its identification, and speaks of it as distinguishable from the preceding only by its inferiority of size, Columna's Sea-star being often a foot in diameter, whilst the diameter of Llhuyd's does not surpass 6 or 7 inches; of the third also he gives a figure, which shows it to be only another variety of the preceding, at the same time quoting the description given by Barrelier[2], who partook of the misapprehension of Columna respecting the use of the dorsal cirrhi, these being likened in function to the proboscis of the Elephant or the upper lip of the Horse. His second genus, named Τρισκαιδεκάκνημος, is based on a specimen described by Petiver[1] as having thirteen arms; this specimen, however, he suspects to have been imperfect. To his third genus he gave the designation *Caput Medusæ*, which had been previously applied to the type since known as *Euryale*; apparently thinking that it might be much more appropriately conferred on Sea-stars having very numerous (sixty or more) straight capillated arms, than on those with ramifying and twining but naked arms, to which he gave the name *Astrophyton*. Of the *Caput Medusæ* he described and figured two species, *brunneum* and *cinereum*, both from the Museum of Seba; these do not seem to differ, however, in anything but size and colour.

---

[1] Johannis Henrici Linckii Lipsiensis 'De Stellis Marinis liber singularis. Tabularum Æncarum Figuras exemplis nativis apprime similes et Autoris Observationes disposuit et illustravit Christianus Gabriel Fischer Regiomontanus.' *Lipsiæ,* 1733.—This work deserves special notice on many accounts. Its author, a Pharmacopolist at Leipzig, was a Foreign Member of the Royal Society, to the President and Fellows of which it is dedicated. The large number of types which are described and admirably figured testify to the industry and zeal of its author as a Collector, who seems to have spared neither pains nor expense in procuring specimens from every quarter of the world; and it is peculiarly interesting to find that a main purpose of the formation of this collection was to throw light on the exact nature of those Fossil remains, whose general resemblance to the Sea-stars was clearly enough recognizable, but whose precise affinities could not be predicated with certainty from anything then known. "In terris per omnem naturalis historiæ memoriam nihil repertum simile; in mari analogiam præ se ferebant viventia aliqua, sub latiore stellarum marinarum genere, ramorum insectorum charactere differentia. Sed nulla hujus generis reperiebatur species, cui quantitas et articulorum configuratio congruebant. Quærendæ stellæ novæ erant, ut instituta cum petrefactis ruderibus collatione, et genus et primæva forma elucerent." (Preface.)—The binomial nomenclature, moreover, is employed more systematically by Linckius, than by any other pre-Linnæan author with whom I am acquainted.

[2] Barrelieri, Jacobi, 'Plantæ per Galliam, Hispaniam, et Italiam observatæ.' *Paris,* 1714.

It is not a little remarkable that notwithstanding the correct approximation of the Crinoïdea by Llhuyd to the nearest type of the Echinoderm group then known, and the prominence given to his views by their incorporation in the important systematic treatise of Linckius, they should have been almost entirely without influence on the opinions of the most eminent Naturalists of the 18th Century. For, to pass by the notion of one that the stems of Encrinites are parts of the vertebral column of certain Fishes, and the idea of another that they are the products of the siphon of Orthoceratites, we find Ellis[2] (in 1753) suggesting that his *Umbellularia Encrinus* (the *Pennatula Encrinus* of Pallas[3]) is the analogue of the *Encrinus liliiformis*, a figure of which he places by the side of that of his "cluster-polype" for the sake of comparison. He seems, however, to have had his doubts of the reality of this resemblance rather strengthened than removed by further inquiry; for in his 'Essay on Corallines' published two years afterwards, we find him, whilst repeating his previous figures, thus expressing himself:—"At K is a figure of the *Encrinos* or *Lilium Lapideum*; which, whether it may not be the petrified *Exuviæ* of this Animal, is submitted to the consideration of the curious in Fossils; for they have not yet been able, I apprehend, to fix upon anything more probable. The difference that appears to me, upon consulting Rosinus, a *German* author, who has published a treatise at *Hamburgh* particularly on this curious fossil, is that the *Encrinos* has rather been a species of Starfish, with a jointed stem or tail; and the rays of the star, instead of having *Tentacula*, or claws, at the end of each, like our Polype, are furnished with ranges of jointed fibres, along the inside of each ray like a brush; of which the same author has given a curious plate, with a particular description of this extraordinary fossil." (*Op. cit.* p. 99.) The notion of the relationship of *Encrinus* to *Umbellularia* and its Zoophytic allies, thus suggested by Ellis, was explicitly adopted by Mylius[4] in a treatise which he published at the same period on the same subject;

---

[1] Petiveri, Jacobi; 'Gazophylacium Naturæ et Artis;' *Londini*, 1711:—also 'Aquatilium Animalium Amboinensium, Icones et nomina;' *Londini*, 1713.

[2] Philosophical Transactions, vol. xlviii. part 1, p. 305.

[3] Elenchus Zoophytorum. *Hagæ Comitum*: p. 365.

[4] Beschreibung einer neuen Grönlandischen Thierpflanze, pp. 16, 17. *Hannover*, 1753, and *London*, 1754.

and it seems to have been generally accepted, notwithstanding ELLIS's own hesitation, since we shall find it to have been the source of the extraordinary misconception in regard to the nature of the CRINOÏDEA adopted by one of the most eminent Zoologists of the commencement of the 19th Century, especially distinguished by his knowledge of Invertebrate Animals.

The discovery of a recent specimen of a pedunculated Crinoid, which was announced by GUETTARD[1] in 1755, did not (as might have been expected) supply the correction of this error; for although he noticed the strong resemblance between this so-called *Palmier marin* and some of the Starfishes described by LINCK, yet being unable to discover a central mouth, he seems to have concluded that this resemblance was fallacious, and to have believed that nourishment was imbibed by the animal through the numerous minute pores which he affirmed to exist at the extremities of the tentacles and pinnules,—thus likening it to the Zoophytic type, although he refrained from ranking it definitely with that group. In his comparison of it with the fossil CRINOÏDEA he made an extraordinary blunder, which was the reverse of that of LISTER; for whilst the latter mistook their summits for radiating and subdividing roots, GUETTARD imagined that the more or less regularly ramifying roots of *Apiocrini* were in reality their summits. Another specimen of the recent *Pentacrinus* very shortly afterwards (1761) came under the notice of ELLIS[2], whose description of it is entitled "An account of an Encrinus or Starfish, with a jointed stem, taken on the coast of Barbadoes, which explains to what kind of animal these fossils belong, called Starstones, Asteriæ, and Astropodea, which have been found in many parts of this kingdom." The specimen examined by him was so imperfect that he did not recognize the place of the mouth; nor did he in any way more distinctly indicate than in the title just quoted the relationship of this organism to the Starfishes. Not having the base of the stem, he felt himself unable to affirm whether it moved freely through the sea, or was attached to the bottom like Corals and Sponges; and it is only by inference that it can be concluded that he was led by the study of this specimen to abandon his previous notion of the relationship of the CRINOÏDEA to "cluster polypes."

It was unfortunate for science that LINNÆUS, instead of adopting the more advanced views of some of his predecessors as to the true relations of the CRINOÏDEA, was so misled by the jointed structure of their stems as to rank them among Zoophytes in the genus *Isis*; whilst he threw back *Antedon* among the other Starfish, ranking them all together in his genus *Asterias*[3]. And this arrangement was left unaltered in the twelfth edition of his 'Systema Naturæ' published in 1766, notwithstanding the appearance of the memoirs of GUETTARD and ELLIS on the recent *Pentacrinus*; nor was it corrected in the edition of the same work subsequently published (1788–1793) by GMELIN.—By BLUMENBACH[1], however, the CRINOÏDEA were correctly placed, in proximity with the recent *Pentacrinus* of GUETTARD, in his division VERMES CRUSTACEA, with which in his later editions he associates the name ECHINODERMATA[2] as a synonym; but he does not in any way recognize *Antedon* as a distinct type having a special relation to the Crinoids.

---

[1] Mémoires de l'Académie des Sciences de Paris, 1755, p. 260.

[2] Philosophical Transactions, vol. lii. part 1, p. 357.

[3] In the tenth edition of the 'Systema Naturæ,' *Holmiæ*, 1758, which is the first in which species are characterized, we find *Comatula* named *Asterias radiata*, and thus strangely described:—"radiis duplicatis, superioribus pinnatis, inferioribus filiformibus." It was long before the difference between the true *rays* and the filiform *cirrhi* came to be understood.

Our *Antedon rosaceus* was described and figured by PENNANT in his 'British Zoology[3],' under the Linnean names *Asterias bifida* and *Asterias decacnemos*; and though no new light was thrown by him either on the peculiarities of its structure or on its affinities, yet it is deserving of notice that he specially alludes to the ventral as well as the dorsal surface being furnished with short simple rays, which are well represented in his figure. These "ventral rays," as LAMARCK afterwards pointed out, are in reality the basal pinnules of the arms, which are much longer than the rest, and (as I shall show hereafter) differ from them very remarkably in structure; but the manner in which they arch over the ventral surface of the central disk is such as to suggest to a superficial observer an analogy to the "short simple rays" or rather "cirrhi" of the dorsal surface.—The *Antedon rosaceus* was again described under the name of *Asterias pectinata* by ADAMS[4], another British zoologist of the latter part of the last century; and his notice of it, though very slight, has this remarkable merit,—that it mentions the existence of two orifices to the digestive cavity. "The body," he says, "is covered on the upper side by five unequal valves." [By this expression he seems to indicate the division of the ventral surface of the disk into five sectors by the radial furrows converging from the bases of the arms.] "It is remarkable of this species that it is furnished with *two* apertures, one at the confluence of the valves, the other in the largest valve; their position with respect to the centre is variable; the last may readily escape observation, except when the animal chooses to elevate it above the plane of the valve." This observation seems to have been completely overlooked by those who subsequently described *Antedon*; its possession of distinct oral and anal orifices having been announced as a new discovery by MECKEL in 1823.

The Class ECHINODERMATA was adopted by CUVIER in his first systematic arrangement of the Animal Kingdom[5]; but this neither contains any recognition of the peculiarities of *Antedon*, nor makes any mention whatever of the CRINOÏDEA. Of the ignorance which still prevailed in regard to the real nature of the last-named group, we have a remarkable illustration in the fact that LAMARCK, in the first edition of his 'Système des Animaux sans Vertèbres' (1801), ranged them, as LINNÆUS had done, among his "Polypes à rayons coralligènes," by the side of *Gorgonia*, *Umbellularia*, and *Pennatula*; apparently under the influence of the original suggestion of ELLIS, and of the erroneous surmise of GUETTARD, who, however, nowhere goes so far as to affirm that the branching arms of his "Palmier marin" actually bear Polypes. It is not a little surprising that, with the very specimen of the recent *Pentacrinus Caput-Medusæ* described by GUETTARD under his eyes in the Museum at the Jardin des Plantes, LAMARCK should have failed to recognize its close relationship to *Antedon*, a type which, as we shall presently see, specially attracted his attention.

---

[1] Handbuch der Naturgeschichte. *Göttingen*, 1780.

[2] The term ECHINODERMATA seems first to have been introduced by KLEIN in his 'Naturalis Dispositio Echinodermatum' published at Dantzig in 1734; but it was limited by him to the *Echini* and their allies, now constituting the family *Echinida*. Not having been able to obtain a sight of the original edition of the 'Handbuch der Naturgeschichte' of BLUMENBACH, I am unable to ascertain whether the term was applied by him to include the *Asteriada* and *Holothurida* before it was so applied by BRUGIÈRE in the 'Encyclopédie Méthodique' in 1792.

[3] Edition of 1776–77, vol. iv. pp. 65, 66, tab. xxxiii. fig. 71.

[4] Linnean Transactions, vol. v. p. 10.

[5] Tableau Élémentaire de l'Histoire Naturelle des Animaux. *Paris*, 1797.

The first among post-Linnean zoologists who recognized the claim of this form of Sea-star to a distinct generic rank, on account of that difference from all others in its plan of structure which had been recognized by LLHUYD and LINCK, seems to have been M. FRÉMINVILLE[1], who in 1811 thus clearly defined the genus, to which he gave the designation *Antedon*:—"Animal libre, à corps discoïde, calcaire en dessus, gélatineux en dessous, environné de deux rangées de rayons articulés, pierreux, percés dans leur largeur d'un trou central; ceux du rang supérieur plus courts, simples, et d'égale grosseur dans toute leur longueur; ceux du rang inférieur plus longs, allant en diminuant de la base à la pointe, et garnis dans toute leur longueur d'appendices alternes également articulés; bouche inférieure et centrale;"—referring for his illustration to the figure in the 'Encyclopédie Méthodique' (pl. cxxiv. fig. 6), which obviously represents the *Stella decacnemos rosacea* of LINCK. Shortly afterwards (1814), and apparently in ignorance of FRÉMINVILLE'S definition, Dr. LEACH characterized this type under the generic name *Alecto*[2]. Both these designations, therefore, have a preferential claim to that of *Comatula*, which was not applied to the genus by LAMARCK until the publication of the second edition of his 'Animaux sans Vertèbres' in 1816. This claim was recognized in regard to *Alecto* by CUVIER, who gave this name the preference to *Comatula*; and also at one time by Professor JOH. MÜLLER, who substituted *Alecto* for *Comatula* in many of his communications to the Berlin Academy; though he afterwards abandoned it in favour of *Comatula* (in ignorance, as it would seem, of the characterization of the genus by FRÉMINVILLE), the name *Alecto* having been in the mean time assigned to a genus of POLYZOA established by LAMOUROUX, and having come to be generally received as its designation. Professor MÜLLER'S adoption of the name *Alecto* seems to have led to its employment by Scandinavian Naturalists, who have continued to use it, notwithstanding its abandonment by Professor JOH. MÜLLER. It is clear, however, that if we are to put aside LAMARCK'S name on the ground of priority, we must go back, not to *Alecto*, but to *Antedon*; and as FRÉMINVILLE'S definition of the genus is at least as correct as that of LAMARCK, it would be contrary to the rules of Zoological Nomenclature, as now understood and acted on, to pass it by. Notwithstanding the appropriateness of

---

[1] Nouveau Bulletin des Sciences, Société Philomathique, tom. ii. p. 349.

[2] Zoological Miscellanies, vol. ii. p. 62.

LAMARCK's name, therefore, and the general acceptance it has met with, I feel constrained to follow the example of Dr. J. E. GRAY, Mr. NORMAN, and Professor WYVILLE THOMSON, in reverting to the previous designation given by FRÉMINVILLE.

Although LAMARCK clearly differentiated *Comatula* as a generic type from *Asterias*, *Ophiura*, and *Euryale*, he was very far from apprehending its most essential peculiarities; and his description of it is strangely incorrect as regards one of its most prominent features, since he not only overlooked the true mouth, but described the anal funnel as the mouth, and placed it in the centre of the disk, which is contrary to the fact. "Au centre du disque inférieur ou ventral des Comatules, la bouche, membraneuse, tubuleuse ou en forme de sac, fait une saillie plus ou moins considérable suivant les espèces. Ce caractère singulier, qu'on ne rencontre jamais dans les Euryales ni dans les Ophiures, semble rapprocher les Comatules de certaines Médusaires." (*Op. cit.* tom. ii. p. 532.) This mistake is the more remarkable, as he expresses surprise at not finding the mouth (where it actually is) at the point of convergence of the furrows which pass from the rays along the ventral surface of the disk:—"Ce sillon, néanmoins, ne s'approche point de la bouche, et ne vient point s'y réunir, comme cela a lieu pour la gouttière des rayons dans les Astéries." He states, on the authority of PERON, that the Comatulæ habitually cling to Fuci or Zoophytes by their dorsal cirrhi, and spread out their rays in search of prey; and he goes on to affirm that they lay hold of this with their "grands rayons pinnés," and bring it to the mouth with their "rayons simples inférieurs." What he means by the last-named organs, I do not feel able to determine with certainty, since the "rayons simples" of his generic definition are "dorsaux" not "inférieurs;" and I am inclined to suppose that he attributes this function to the pinnules springing from the basal joints of the arms, which, as he correctly remarks, are "allongées et abaissées sous le ventre." I feel confident, from observation of the habits of the living animal, that these pinnules are no more employed in the prehension of food than are the principal arms; and I am inclined (as will hereafter appear, § 13) to regard that peculiarity of their character and disposition, which LAMARCK was the first to notice, as connected with the sensorial protection of the oral orifice.

In this edition we still find LAMARCK ranking the CRINOÏDEA among Polypes; though he separates them, together with *Pennatula*, *Umbellularia*, &c., into a distinct group, that of *Polypi natantes*. He speaks without hesitation of their ramified arms as bearing polypes arranged in rows (!), and remarks that they are especially distinguished from *Pennatulæ* and other genera of the order of floating Polypes by the articulated structure of the stem and branches. "Les Encrines," he says (*op. cit.* p. 434), "se rapprochent de l'Ombellulaire par leur ombelle terminale et polypifère; mais leur tige et leur rameaux articulés, enfin la disposition des Polypes qui forment des rangées sur les rameaux de l'ombelle, les en distinguent fortement." It is singular that so eminent a Naturalist could have committed himself to a misstatement of fact so extraordinary as that just cited.

The publication of LAMARCK's work was very soon followed by that of the first edition (1817) of the 'Règne Animal' of CUVIER, in which the CRINOÏDEA are included (after the example of BLUMENBACH) in the class ECHINODERMATA; being placed at the end of the family *Asteriada*, in immediate sequence to *Gorgonocephala* (*Euryale*) and *Alecto* (*Antedon*). And this position they have retained in all subsequent systems of classification; the only difference of opinion having been as to the intimacy of the relationship between the Crinoïdea and other stellate forms of Echinodermata.

The year 1821 constitutes an important epoch in this history; being that of the publication by J. S. MILLER, a German naturalist residing at Bristol, of the 'Natural History of the Crinoïdea';—a work which laid the foundation of the scientific study which the group has since received on the part of various distinguished zoologists. Bringing together all the forms already known, and adding to these a large number first examined by himself, the author sought, in a careful comparison of their structural characters, a valid basis for their systematic arrangement; and the principles he developed have been followed (with some modifications in detail) by all who have since applied themselves to the same line of study, whilst the genera he created have been universally accepted as well-marked natural groups. The most faulty part of his system was the nomenclature he conferred on the several pieces of which the cup and arms are composed; this being drawn from the osseous skeleton of Vertebrata, to which the framework of the Crinoïdea has no kind of analogy. At the conclusion of his description of the CRINOÏDEA, MILLER enters upon the consideration of their precise relationship to the several types included by LAMARCK in his family *Stellerida*; and after a careful comparison of their characters with those of the genera *Asterias*, *Ophiura*, and *Euryale*, he comes to the conclusion that with neither of these have the CRINOÏDEA any close affinity. He then proceeds to the like comparison with *Comatula*, the results of which, he says (p. 127), "were even more favourable than the first appearances had given me reason to hope, presenting, indeed, a conformity of structure almost perfect in every essential part (except the column which is wanting, or at least reduced to a single plate), and exhibiting an animal which would be defined with sufficient precision as a *Pentacrinus* destitute of the column." The species of *Comatula* investigated by MILLER, though designated by him *C. fimbriata*, is closely allied to, if not identical with, the *rosacea* of LINCK; the specimens of it which he examined were from Milford Haven. His description is generally accurate as far as it goes, but it includes little else than the skeleton. He makes no mention of the true oral orifice, except to state that he could not detect in his dried specimens the pentagonal mouth figured by PENNANT; and it is obvious that, like LAMARCK, he was misled by the prominence of the anal funnel into supposing it to be the mouth. To MILLER, then, is distinctly due the credit of having first maintained, since LLHUYD, upon the basis of an exact comparative appreciation of the characters furnished by the skeleton, that among all the recent STELLERIDA, the only type which bears any close correspondence to the CRINOÏDEA is *Antedon* (*Comatula*); and that its relationship to the Crinoids is so intimate as to require its being included with them in the same family. He did not, however, propose to remove this family from the Order *Stellerida*, being ignorant of those peculiarities in its digestive and reproductive apparatus which are now generally admitted to entitle the CRINOÏDEA to rank as a group of ordinal value.

The first approach to a knowledge of these peculiarities was made by MECKEL[1], who pointed out that the alimentary canal is provided with two orifices: the mouth, which is nearly central, but inconspicuons; and the anus, which is prominent but eccentric. In ignorance, apparently, of what had been previously advanced by MECKEL, Dr. J. E. GRAY[2] in 1826 drew attention to the existence of a double orifice to the alimentary canal, and to the importance of this character in classification. And in the same year a more complete elucidation of this part of the structure of *Comatula* was effected by HEUSINGER[3].

In 1827 the remarkable discovery was announced by Mr. J. V. THOMPSON[4] (by whom it had been made four years previously) of a true pedunculate Crinoid, to which he gave the name *Pentacrinus Europæus*, living in the Cove of Cork. His examination of its structure enabled him to affirm its intimate resemblance, on the one hand to *Comatula*, and on the other to the ordinary *Crinoids*; and it is interesting to observe that he had been led, by noticing its possession of a double orifice to its alimentary canal, to the recognition of the like conformation in *Comatula*—a discovery which was thus made independently and nearly contemporaneously by Professor MECKEL, Dr. J. E. GRAY, and Mr. J. V. THOMPSON. He does not limit himself to the description of that which he considers the perfect form of this organism; but gives an account, which though slight is very characteristic, of the principal phases of its development, commencing with that in which "the animal resembles a little club, fixed by an expanded basis, and giving exit at its apex to a few pellucid tentacula, no other part of the solid fabric being observable but an indistinct appearance of the perisome;" and he sagaciously adds, "From these observations connected with the growth of this animal, and by which it appears to present itself at various stages of its progress under considerable diversity of form, naturalists may learn to avoid the unnecessary multiplication of the genera and species of the Crinoïdea by giving undue weight and consideration to characters originating in the progressive evolution of individual species, and which are consequently of a transitory and delusive nature."

One of the most important contributions hitherto made to our knowledge of the anatomical structure of *Antedon*, was the memoir of HEUSINGER, 'Anatomische Untersuchung der *Comatula mediterranea*,' published in 1829[5]. This is, for the most part, extremely exact in its details, so far as these extend; being chiefly deficient in regard to points which the use of the microscope alone can determine: and among the excellent figures by which it is illustrated, are admirable sectional views of the structure of the visceral disk, which much surpass those subsequently given by Professor JOH. MÜLLER. I shall have frequent occasion to refer to HEUSINGER'S memoir, when I come to describe the digestive apparatus of *Antedon.*

---

[1] "Ueber die Oeffnungen des Speisekanals bei den *Comatulen*," in MECKEL's 'Archiv für Physiol.,' Bd. VIII. (1823) p. 470.

[2] "Notice on the digestive organs of the genus *Comatula*, and on the *Crinoïdea* of MILLER," in 'Annals of Philosophy,' N. S., vol. xii. (1826) p. 392.

[3] "Bemerkungen über den Verdauungskanal der *Comatulen*," in MECKEL's 'Archiv für Physiol.' (1826), p. 317.

[4] Memoir on the *Pentacrinus Europæus*: a recent species discovered in the Cove of Cork, July 1, 1823. With two plates. By JOHN V. THOMPSON, F.L.S. Cork, 1827.

[5] HEUSINGER's 'Zeitschrift für organ. Physiol.', Bd. III. p. 366.

In 1834 M. DE BLAINVILLE published his 'Manuel d'Actinologie,' in which the relations of the CRINOÏDEA to the other members of the Order STELLERIDA are carefully examined and set forth. He divides that Order into three Families, *Asteridea*, *Asterophydea*, and *Asterencrinidea*; and of the latter he says (p. 248), "C'est à l'intéressante découverte faite par M. THOMPSON d'une très-petite espèce d'Encrine vivante, sur les côtes d'Irlande, et à son Mémoire à ce sujet, que nous devons la possibilité d'établir et de caractériser cette famille d'une manière convenable, en nous appuyant aussi sur le travail *ex professo* de M. MILLER sur les Encrinites fossiles." Further on he says of Mr. THOMPSON'S discovery (p. 256), that he "a détruit toute espèce de doute sur la place des Encrines vivantes ou fossiles, et a démontré clairement la justesse de la manière de voir de ROSINUS, adoptée par GUETTARD, ELLIS, PARKINSON, et M. CUVIER, contre celle de LINNÉ, suivie par M. DE LAMARCK. Une Encrine n'est pour ainsi dire qu'une Comatule renversée, en supposant même que cette position ne soit pas également naturelle à celle-ci, ce que je suis fortement porté à penser, et qui, au lieu de se cramponner à l'aide des rayons accessoires, est fixée par le prolongement de la partie centro-dorsale." He divides his family *Asterencrinidea* into two groups, the *free* and the *fixed*; the only representative of the first being *Comatula*, whilst in the second he includes all MILLER'S genera of Crinoids, with the addition of the genus *Phytocrinus*, which he created for the reception of Mr. J. V. THOMPSON'S *Pentacrinus Europæus*, regarding it (and with reason) as not properly referable to the genus *Pentacrinus.* He enters at length into the structure of *Comatula*, the skeleton of which he describes correctly enough, whilst in regard to its soft parts he falls into some remarkable errors. Thus he states that the furrow which runs along the axis and the lateral pinnules of each arm is provided with "cirrhes ventousaires," which serve to enable the animal to seize its prey; the fact being that these tentacula are not in any degree prehensile, and have no concern whatever in the acquisition of food. Again, whilst correctly describing the mouth, he states that the stomach has no second orifice, but terminates posteriorly in a blunt point; and that which LAMARCK regarded as the mouth, and which English authors had rightly taken for an anus, he affirms to have no connexion with the alimentary canal, but to be a prolongation from the "general cavity of the body," adding the suggestion that it may be the respiratory outlet, or may be subservient to the function of locomotion, or may be the termination of the oviducal canal. On this point he confesses himself unable to speak confidently, not having succeeded in discovering ovaries in the only individual which he dissected; but he surmises that in changing its place the animal may make use of its "vessie abdominale," contracting it upon the water with which it had been previously filled, after the manner of Cuttle-fish. He rightly stated that *Comatulæ* attach themselves to fixed objects by means of their "accessory rays" (or dorsal cirrhi), and that they extend their principal rays in every direction; but in asserting that this is "pour atteindre et pour attirer la proie vers l'orifice buccal," he simply hazards a supposition for which there is not any foundation in fact, the arms not being used for the purpose of grasping food or of conveying it to the mouth. It is obvious that M. DE BLAINVILLE was entirely unacquainted with the excellent description of the alimentary canal previously given by HEUSINGER; and that he stated as facts what were only his own conjectures.

Not many years after Mr. THOMPSON'S publication of his *Pentacrinus Europæus*, he ascertained that it is nothing else than the young of the *Comatula*, to which he had previously noticed its close resemblance. This discovery he communicated to the Royal Society in a "Memoir on the Star-Fish of the genus *Comatula*, demonstrative of the *Pentacrinus Europæus* being the young of our Indigenous Species"[1], which was read on the 18th of June 1835, but was not published in the Philosophical Transactions. The evidence which he adduces on this point is drawn from the resemblance between the most advanced specimens of *Pentacrinus* and the youngest *Comatulæ*, which is so close as to leave no reasonable doubt of the development of the former into the latter. Mr. THOMPSON also describes in this Memoir the development of the ova in conceptacles formed by the thickening of the membranous expansion inside each of the first fifteen or twenty pairs of pinnæ. The ova, he says, "make their exit through a round hole on the fascial side of each conceptaculum, still, however, adhering together in a roundish cluster of about a hundred each;" and he adds "by what means these ova are dispersed, or how they become attached to the stems and branches of corallines, remain to be discovered." He surmised that the parent must be gifted with the power of placing them in appropriate situations; and that from "the dispersed and attached ova" the young *Pentacrini* at once shoot up,—a supposition which was extremely natural at the period he wrote, not the least suspicion that the first product of the embryonic development of the ECHINODERMATA generally is an active free-swimming pro-embryo, having at that time been hazarded by any Naturalist.

In the same year (1835) some important observations on *Comatula* were published by M. DUJARDIN[2], who had watched the animal in a living state at Toulon. Like Mr. THOMPSON, he noticed the development of the ova in the swollen pinnules, and their escape through apertures which form in the integument. He also stated correctly that these animals habitually live attached to Sea-weeds, Zoophytes, &c.; only swimming occasionally for the purpose of changing their place of attachment. And he recognized the fact that the arms are not prehensile, and that the food is obtained through an agency altogether distinct from that of which other Star-fish avail themselves; but of that agency he gave an entirely erroneous account (which he subsequently withdrew), being ignorant of what microscopic examination has since revealed as to the ciliary action by which the ingestion of food is really accomplished. An examination of the residual matters ejected through the anal orifice enabled him to determine that these were spicules of Sponges, Bacillariæ, and remains of other microscopic organisms.

---

[1] Edinburgh New Philosophical Journal, vol. xx. (1835–36), p. 295.

[2] L'Institut, No. 119 (1835), p. 268.

In the same year also there appeared the "Prodrôme d'une Monographie des Radiaires ou Echinodermes" of Professor AGASSIZ; which left the position of *Comatula* among the Crinoïdea, and of the *Crinoïdea* as a family of the STELLERIDA, very much the same as in BLAINVILLE'S arrangement.

We next come to the memoir of Professor JOH. MÜLLER, "Über den Bau des *Pentacrinus Caput-Medusæ*," communicated to the Berlin Academy[1] on the 30th April, 1840, and the 13th May, 1841; which constitutes the most important contribution that has been made up to this time, not only to the anatomy of the CRINOÏDEA generally, but to that of *Antedon* in particular; the structure of that type having been carefully investigated by Professor MÜLLER, with the view of throwing light on that of the parts of his specimen of *Pentacrinus* which were unfortunately deficient, as well as for the sake of determining the precise relations of these two genera. I shall have such constant occasion in the subsequent portions of the present communication to refer to the labours of my distinguished predecessor, that I shall here only express my high appreciation of their value, and my regret that he did not himself live to supply that completion and extension of them, for which he is understood to have collected materials during a visit he made to the coast of Norway, shortly before his death, for the purpose of studying *Antedon* in its living state. His investigation of the skeletons of *Pentacrinus* and of *Antedon*, and of the relations of their different parts as indicated by their muscular connexions, was conducted in a thoroughly philosophical spirit; and afforded the basis for a more satisfactory determination of the homologous parts in the fossil CRINOÏDEA than had been possible on the comparatively empirical method of J. S. MILLER. The nomenclature which he introduced has completely superseded that of his predecessor; and, with some modifications, it will probably remain as the standard by which all descriptions of CRINOÏDEA will be drawn. In subsequent communications to the Berlin Academy, which are all embodied in his Memoir "Über die Gattung *Comatula* und ihre Arten"[2], he laid down the principles on which he considered that the systematic arrangement of the numerous species now known might best be founded; and he gave descriptions of these species, based on the characters thus indicated, and for the most part drawn from personal examination of the specimens contained in the principal European museums.

It was by Professor EDWARD FORBES that the title of the CRINOÏDEA to rank as a distinct *Order* of Echinodermata seems to have been first perceived; and in his 'History of British Star-fishes, and other Animals of the Class Echinodermata,' published in 1841, he constituted such an Order under the title of PINNIGRADA, which he conferred upon it in conformity with his fundamental idea of classifying Echinodermata, like Arachnodermata, according to "the modifications of their organs and modes of progression." He does not enter into any explicit justification of the claims either of the CRINOÏDEA or of the OPHIURIDA to the ordinal rank here first assigned to them; but contents himself with remarking that "as an explanation of the true nature and relation of the Echinodermatous tribes, I prefer it to any arrangement at present used, and have accordingly followed it throughout this work." There can now be no doubt that Professor FORBES was completely justified in separating the CRINOÏDEA from the STELLERIDA with which they had been previously associated; since they differ entirely from the *Asterida* and the *Ophiurida* in the conformation both of their digestive and of their generative apparatus; whilst their resemblance to those groups is only such as springs from the general disposition of the parts of their skeletons, the fundamental homologies of which are altogether diverse. And in accordance with his views, a rank corresponding to that of ECHINIDA and ASTERIADA has been assigned to the CRINOÏDEA by the general consent of subsequent systematists; as D'ORBIGNY[1], VAN DER HOEVEN[2], PICTET[3], BRONN[4], DE KONINCK and LE HON[5], and DUJARDIN[6].

---

[1] Abhandlungen der Königl. Akademie der Wissenschaften zu Berlin, 1841.

[2] Abhandlungen der Königl. Akademie der Wissenschaften zu Berlin, 1847.

The account which Professor EDWARD FORBES gave of *Comatula rosacea* appears to have been written without any knowledge of the previous anatomical investigations of HEUSINGER, and was issued before those of Professor MÜLLER had been communicated to the Berlin Academy. It is for the most part confined to the external characters of the animal, which are in general correctly described, though not with the minuteness which could only be attained by a more elaborate microscopic investigation than Professor FORBES seems to have bestowed upon the details of its structure. He rightly apprehended the relative characters of the mouth and anus; and with respect to the latter he remarks, "This curious vent has been mistaken by many authors for the mouth, and has greatly puzzled others; and M. DE BLAINVILLE suggested that it might be connected with the functions of respiration or generation: but any one who examines the *Comatula* alive, or dissects a specimen well preserved, will not doubt it is a true vent." He made, however, a most extraordinary mistake in regard to the ovaries; for notwithstanding the very explicit statement of Mr. J. V. THOMPSON (which he quotes) as to the liberation of the ova from conceptacles formed by the swelling of the pinnæ, he affirms that only spermatozoa are formed in these conceptacles, and that the real ovaries are certain "round brown dots, placed in regular rows and at regular distances along the margins of the canals, on the body, the arms, and the pinnæ." What is the true nature of these spots, is a question which will be considered hereafter; it may be positively affirmed, however, that they are *not* the ovaries, since the production of the ova in the swollen portions of the pinnæ has been seen not merely by Mr. J. V. THOMPSON, but by M. DUJARDIN, Professor MÜLLER, Dr. BUSCH, Professor WYVILLE THOMSON, and myself. The fact is that these animals are unisexual; and that while ova are produced in the conceptacles of some individuals, spermatozoa are developed within others, and are set free in the same mode.

---

[1] Cours Elémentaire de Paléontologie et de Géologie Stratigraphiques. Paris, 1849.

[2] Handbook of Zoology, translated by Professor CLARK. London, 1856.

[3] Traité de Paléontologie, 2ième Ed. Paris, 1857.

[4] Die Klassen und Ordnungen des Thier-Reichs. Zweiter Band. Leipzig und Heidelberg, 1860.

[5] Recherches sur les Crinoïdes du Terrain Carbonifère de la Belgique. Bruxelles, 1854.

[6] Histoire Naturelle des Zoophytes Echinodermes. Paris, 1862.

The statement of Mr. J. V. THOMPSON as to the identity of his *Pentacrinus* with the young of *Comatula*, on which doubts had been cast by M. DUJARDIN[1], was satisfactorily confirmed by Professor FORBES. "When dredging in Dublin Bay," he says (Introduction, p. xii), "in August 1840, with my friends Mr. R. BALL and W. THOMPSON, we found numbers of the Phytocrinus or Polype-state of the Feather-star, more advanced than they had ever been seen before, so advanced that we saw the creature drop from its stem and swim about a true Comatula; nor could we find any difference between it and the perfect animal, when examining it under the microscope." He did not, however, add anything to the account previously given by Mr. J. V. THOMPSON of the successive stages of development of this Pentacrinoid larva; and his description of the structure of its calcareous stem is very far from being accurate, as I shall have occasion to show hereafter.

The remarkable discoveries of Professor MÜLLER and other observers in regard to the larval or pro-embryonic forms of ECHINIDA, ASTERIADA, and OPHIURIDA, naturally led to the suspicion that some corresponding form of free-swimming pro-embryo must be the first product of the egg of *Antedon*; and that this probably gives origin to the Pentacrinoid larva by a process somewhat similar to that by which the young *Echinus* originates from its "pluteus," or the *Asterias* from its "bipinnaria." To the solution of this problem Dr. WILH. BUSCH[2], a pupil of Professor MÜLLER, applied himself in 1849; and he was fortunate enough to discover such a free-swimming pseudembryo, somewhat Annelidan in its form; though he did not succeed in tracing it beyond its earliest stages, or in showing how the Pentacrinoid larva originates from it. It is probably through not having done so, that his interpretation of his observations was in many points incorrect; as has been shown by the more recent and complete researches of Professor WYVILLE THOMSON[3], who has worked out this part of the developmental history of *Antedon* with a completeness that leaves scarcely anything to desire, and who (in accordance with my request) has not only traced the metamorphosis of the free-swimming pseudembryo into the pedunculate Crinoid, but has carried on the description of the latter to the stage at which my own observations best enable me to take it up.

In 1856 an account was published by Professor SARS of the Pentacrinoid stage of *Antedon Sarsii*; but as the principal points of interest in this communication have already been noticed in Professor WYVILLE THOMSON'S Memoir (p. 516), I need not here repeat them. As he justly remarks, it would appear from Professor SARS's description that the pedunculate condition is much more prolonged in *A. Sarsii* than in *A. rosaceus*; the animal being only distinguishable by the persistence of its stem from an adult *Antedon*.

---

[1] L'Institut, No. 119 (1835).

[2] "Ueber die Larve der *Comatula*," in Müller's Archiv, 1849, p. 400; and in Beobachtungen über Anatomie und Entwickelung einiger wirbellosen Seethiere. Berlin, 1851.

[3] "On the Embryogeny of *Antedon rosaceus*," in Philosophical Transactions for 1865, p. 513.

Early in 1863 Professor ALLMAN communicated to the Royal Society of Edinburgh[1] a Memoir "On a Prebrachial stage in the development of *Comatula*," based on the observation of a single specimen which he had obtained on the coast of South Devon; and he was the first to publish the very interesting fact that the plates first formed in the Pentacrinoid larva are the circlet of *basals* and the circlet of *orals* superimposed on them, the former constituting the calyx, and the latter forming its pyramidal roof; the only vestige of the *radials*, which are afterwards to constitute the essential part of the skeleton, being a set of five minute plates intercalated between the upper angles of the basals. This disposition he compares with that of the plates in certain fossil CRINOÏDEA, which in his opinion permanently represent a condition that is transitory in our Pentacrinoid larva. His account of the tentacular apparatus, however, bears evidence of the insufficient opportunities for observation afforded him by the possession of a single specimen; and I feel bound to state that having myself verified Professor WYVILLE THOMSON's descriptions,—which are based on frequently-repeated observations made upon an ample supply of specimens, and these not merely in the phase of development which fell under Professor ALLMAN's notice, but in all the preceding and subsequent stages,—I am quite satisfied of their correctness on all those points in which they differ from the descriptions of Professor ALLMAN.

The foregoing constitute, I believe, all the contributions hitherto made to our acquaintance with the structure and physiology of *Antedon*; and it only remains for me to notice two recent works, one on the CRINOÏDEA, the other on the ECHINODERMATA generally, in which its relations to the Crinoids and to other Echinoderms are discussed with all the advantage of more advanced knowledge.

The first of these is the memoir of MM. L. DE KONINCK and H. LE HON, entitled "Recherches sur les Crinoïdes du Terrain Carbonifère de la Belgique"[2], which is much more comprehensive than its title would indicate, since it contains an elaborate History of the progress of knowledge as to the CRINOÏDEA generally (to which I have already had occasion to refer, p. 675), and a philosophical investigation of their Zoological relations, and of the principles on which the classification of the group should be founded. Their inquiries have led them to a modification of the nomenclature of Professor MÜLLER, which will, I believe, be found practically convenient, and which, therefore, I shall follow in my own description. The only addition to our knowledge of the recent *Crinoïdea* which this memoir contains, is furnished by a previously unpublished communication from M. DUCHASSAING to M. MICHELIN, accompanying a specimen of *Pentacrinus Caput-Medusæ* transmitted by him from Guadaloupe. "La bouche de l'Encrine se trouve circonscrite par cinq lèvres. Elle ne se voit que lorsqu'on a soulevé ces cinq lèvres. On voit alors que c'est un petit trou rond d'environ deux lignes de diamètre. Les lèvres ne sont libres, et ne peuvent être soulevées que de trois lignes environ. Dans le reste, elles sont adhérentes par les cinq sillons qui partent des commissures et se prolongent jusqu'à la circonférence du disque. La mastication ne s'opère pas par la bouche, mais bien par les lèvres, qui sont armées à cet effet d'une rangée de petites épines assez fortes. Quant à la nourriture, j'ai trouvé des débris de petits crustacés." This statement is important, since the imperfection of the specimen of *Pentacrinus* described by Professor MÜLLER prevented him from giving any account of the parts about the mouth; but the correspondence of the peripheral part of the disk with that of *Comatula* led him to infer that the central portions are constructed on the same plan,—the validity of which inference is confirmed by the description just cited. It further appears from the reference made by our authors to the sketches of M. DUCHASSAING, that the mouth of *Pentacrinus Caput-Medusæ* is surrounded by Oral plates, similar in form to those which exist in the Pentacrinoid larva of *Antedon*, though no trace of them is to be found in the adult. I do not, however, regard the evidence as yet sufficient to establish this conclusion.—In regard to the fossil CRINOÏDEA, MM. DE KONINCK and LE HON made an important step in advance of their predecessors in strongly drawing attention to the single, double, or multiple *anal* plate, as a peculiar feature in the skeleton, introducing a bilateral symmetry in what would otherwise be regularly radial. Their determination of the nature of this plate is fully borne out by its position in the Pentacrinoid larva of *Antedon*, although, like the oral plates, it is wanting in the adult.

---

[1] Transactions of the Royal Society of Edinburgh, vol. xxiii. p. 241.

[2] Mémoires de l'Académie Royale de Belgique. Bruxelles, 1854.

Of the recent systematic treatise by MM. DUJARDIN and HUPÉ on the ECHINODERMATA generally[1], it is only needful to say that whilst it furnishes a convenient *résumé* of previous researches upon the Order CRINOÏDEA and upon the genus *Comatula* (which, as in D'ORBIGNY'S arrangement, is taken as the type of a distinct Family, *Comatulidæ*), it adds nothing to our knowledge of them. In their systematic arrangement and description of the species of *Comatula*, these authors for the most part follow Professor MÜLLER.

III.—EXTERNAL CHARACTERS, AND HABITS:—SYNONYMY.

1. In common with other members of the Family COMATULIDÆ, our *Antedon* may be described generally as composed of a central disk, from which radiate ten slender arms, fringed with pinnules along their entire length (Plate XXXI.). The disk contains the whole of the proper Digestive apparatus, which forms a lenticular mass lying in the hollow of a shallow calcareous basin or *Calyx*, and entirely exposed on its oral surface,

---

[1] Histoire Naturelle des Zoophytes Echinodermes, comprenant la description des Crinoïdes, des Ophiurides, des Astérides, des Échinides, et des Holothurides. Par M. F. DUJARDIN et M. H. HUPÉ. (Suites à Buffon.) Paris, 1862.

which is covered only by the membranous *Perisome*. The centre of the visceral disk is occupied by the Mouth (Plate XXXII. fig. 3, *m*), which is small and slightly prolonged into five angles; and is surrounded by five somewhat elevated valvular folds, beneath the free edge of each of which is to be seen a row of minute tentacula. From the mouth there radiate five furrows channelled out in the perisome, and having elevated borders scolloped so as to form a series of minute valvules, from beneath each of which issues a cluster of three tentacles; these furrows soon bifurcate, and thus ten furrows are formed, of which one is continued on to the ventral surface of each of the arms in the extension of the perisome which clothes it. In the space between two of these furrows we see the large projecting vent or Anus (*a*), the shape of which differs much according as it is full or empty; sometimes its aperture is so completely closed as to be scarcely discernible, though the tube below is widely distended; whilst in other states we find the aperture patent, its edges everted and crenate, and the tube leading to it quite shrunk and flaccid.—On looking at the dorsal or aboral face of the central disk, which in the living state is ordinarily the inferior, we find it in great part concealed by an assemblage of jointed and uncinate *Cirrhi*, radiating from a central tubercle to which they are articulated (Plate XXXII. fig. 4), and extending even beyond the margin of the disk: the number of these ordinarily ranges in a full-grown specimen between twenty and thirty-two; and each of them normally consists of about sixteen segments. When these have been removed, we find the under surface of the calyx to be composed, as shown in Plate XXXII. fig. 1, of a single convex *Centro-dorsal* plate (*c*), having a somewhat pentagonal margin, within which are two or more rows of sockets for the articulation of the cirrhi, whilst the central space, which bears no cirrhi, is somewhat flattened. Along the five sides of this pentagon we see five pieces (r^2) having their proximal and distal margins nearly parallel, but their surfaces convex; these are the *Second Radials*, the *First* being entirely concealed by the Centro-dorsal. And to the distal margins of the second radials are attached five pieces (r^3) of nearly triangular form; their basal margins rather exceeding in length the distal margins of the second radials to which they are applied; whilst each of their inclined sides bears the first segment (br^1) of an Arm: these triangular pieces are the *Third* or *Axillary Radials*. The spaces between the diverging Radials, and between the basal segments of the Arms as far as the fourth, are filled up by the membranous Perisome, which thus completes the floor of the calyx. Sometimes, however, we find minute plates imbedded in the substance of the perisome, at the angles between the second radials (§ 9).

2. Each Arm is composed of a long series of calcareous segments, of which the dorsal surface is exposed like the dorsal surface of the calyx, whilst the ventral surface is clothed with an extension of the ventral perisome, carrying with it an extension of the radial furrows and their tentacular apparatus. With certain exceptions, hereafter to be noticed, every segment of the arms bears a jointed Pinnule, which repeats on a smaller scale the same structural features; and the furrows which pass from the disk to the arms, send branches also from the arms to the pinnules, which are continued to their

extremities. Along the borders of these furrows there extend from the inner margins of the valvular folds which fringe them, groups of delicate tubular tentacula; each group consists of three, of which one is peculiarly extensile.—The pinnules are borne on the opposite sides of the successive segments of the arms, so that they present an *alternate* arrangement. Those belonging to the basal segments of the arms (Plate XXXII. fig. 3) assist in supporting the visceral mass, and during life they are observed to arch over the disk (Plate XXXI. A) instead of projecting laterally like the rest; they are, moreover, peculiar in being about twice as long as those which succeed them, and in being entirely destitute of the tentacular apparatus. The succeeding pinnules, at the season of reproduction, become turgid in consequence of the development of the ovaries or testes in their substance, as already described by Professor WYVILLE THOMSON.

3. When the visceral mass has been removed from the calyx, which is very easily accomplished by tearing away the perisome that closes round its margin, we find the floor of the basin (Plate XXXII. fig. 2) nearly smooth, but depressed in the centre, where there is a passage through the calcareous pentagon formed by the union of the *First Radials*, which passage is occupied by a soft pedicle. This pedicle we shall hereafter find to establish a connexion between the visceral mass and certain structures contained in the cavity of the centro-dorsal plate; and it is to be regarded as the residue of the original Crinoidal axis. At a little distance from the central passage we see five pairs of Muscles arranged pentagonally; these pass between the first and the second Radials. On the distal side of each of these we see two pairs of muscles, diverging from each other; these pass between the third Radials and the first Brachials,—the second and third Radials being connected by ligamentous union only (see § 37 and Plate XXXIV. fig. 2).

4. The Colour of our *Antedon* varies greatly. Commonly it is that which its trivial name *rosaceus* implies; but the crimson frequently deepens to a rich damask hue, especially during the breeding-season; whilst it very frequently gives place to white on portions of the disk and arms, so that the animal has a beautifully variegated aspect. Sometimes, again, the predominant hue is a rich orange, and this may be variegated with white or crimson, or with a bright sulphur-yellow. This last is often the first colour assumed by the Pentacrinoid larvæ, when not far from the termination of their pedunculate stage.

5. The Size of our *Antedon* also varies within a wide range. Its usual diameter from tip to tip of its extended arms may be from 4 to 5 inches, but specimens exceeding this limit are by no means uncommon; and I have occasionally met with specimens as much as 9 inches in diameter. As I am certain that these last were identical in structure with the ordinary type, I cannot regard an excess of size as affording adequate ground *per se* for specific differentiation.

SYNONYMY.

6. Referring to the memoir of the Rev. A. M. NORMAN "On the Genera and Species of British Echinodermata"[1] for definitions of the Order CRINOIDEA, the Family ANTEDONIDÆ, the Genus *Antedon*, and the Species *rosaceus*, I have now to state my views on its synonymy. As to this I am not able to speak with the positiveness I could desire, since my investigations, though prosecuted over a considerable Geographical range, have not yet satisfied me as to the *limits of variation* in this type. In this, as in many similar cases, points of difference which seem extremely well marked when the most divergent examples from remote localities are compared, are found, when a sufficiently large number of examples from intermediate localities are examined, to present gradational modifications which go far to destroy their value as specific characters. And this will be found especially the case with those characters which rest on *degree of development*. Thus I can attach little value to the flattening of the Centro-dorsal plate (§ 22) in one type, and its uniform convexity in another,—or to the nakedness of the flattened portion in the former, whilst the whole surface is covered with dorsal cirrhi in the latter;—when I find that in the early stage of both, the centro-dorsal plate is uniformly convex and entirely covered with dorsal cirrhi, so that young specimens of the two could not be differentiated. Nor can I adopt as characters of specific difference such variations in the number of Dorsal Cirrhi, the number of their joints, the proportion of the length of these joints to their breadth, and the form of their terminal claw, as I occasionally meet with among the cirrhi of specimens from the same locality resembling each other in all other respects; the shedding and renewal of these cirrhi continuing, in my opinion, through

---

[1] The following are given by Mr. NORMAN (Annals of Natural History, 3rd Series, vol. xv. p. 102) on the authority of Professor WYVILLE THOMSON, as the diagnostic characters of *Antedon rosaceus*:—"Perisom of the disk naked, or with scattered tubercles containing groups of radiating calcareous spicules. Centro-dorsal plate convex, flattened at the apex, its sides covered with dorsal cirrhi; but the central flattened portion, of greater or less extent, naked. Cirrhi 14–18-jointed; the joints short, the longest but little longer than broad. Terminal claw sharp and curved; penultimate joint with a short pointed opposing tubercle, which is not developed into a claw. Proximal pairs of pinnules at least twice as long as those succeeding. Ovaries short and rounded. Usually, when mature, without any trace of interradial plates; frequently, however, with groups usually of three perisomatic interradial plates in the spaces between the radial axillaries. Colour crimson, scarlet, or mottled. Average size 4½ inches from tip to tip of arms."—Of *Antedon Milleri* the following are given as characters:—"Perisom of the disk with scattered warts, supported by groups of diverging spicules. Centro-dorsal plate uniformly convex, and entirely covered with dorsal cirrhi. Cirrhi 15–18-jointed; the longest of the joints about once and a half as long as broad. Terminal claw curved and acute; penultimate joints without a trace of an opposing process. Proximal pinnules greatly longer than those succeeding them. Ovaries long and narrow, extending over more than half the length of the pinnules. Groups of interradial plates occupying the spaces between the radial axillaries. Of a rich brown or reddish-tawny colour. Average size 11 inches from tip to tip of the arms."—None of these characters appear to me sufficient for the differentiation of the two species to which they are respectively assigned, save the form of the ovaries, which (as Professor WYVILLE THOMSON assures me) constitutes a strongly marked feature in each, and is not liable to gradational variations like Size, Colour, the form and relative abundance of the Perisomatic plates, or to variations connected with grade of development like others alluded to above.

the whole life of the animal; and the several cirrhi of the same individual often presenting very marked differences in size and proportions (§§ 26–30). Even a character which in the first instance appeared so definite as the presence of interradial plates in one type (as in the *Comatula fimbriata* of J. S. MILLER), and their entire absence in another (the *Comatula rosacea* of FLEMING and EDWARD FORBES, the *Antedon decameros* of GRAY, the *A. rosaceus* of NORMAN, WYVILLE THOMSON, and myself), has proved unreliable, as I shall hereafter fully explain (§ 39). And thus I am led to suspect that the range of variation in this type is very wide, and that the more extended the comparison of specimens from different localities and from different depths, the more reason there will appear for assigning only a *varietal* rank to several types which are at present accounted different *species*.

7. As there can be no reasonable doubt that the type which forms the subject of this memoir is the one described by LINCK[1] under the name *Stella decacnemos rosacea*, "propter corporis fabricam rosæ similem," and as the treatise of LINCK is the foundation of all our scientific knowledge of the group of Sea-stars, his specific name has a preferential claim to our acceptance, which has been already recognized by FLEMING[2], BLAINVILLE[3], and EDWARD FORBES[4]. With EDWARD FORBES I am disposed to consider the *Stella decacnemos barbata* of LINCK (the *fimbriata* of BARRELIER, whose figure and description he cites) as specifically identical with his *rosacea*, although FLEMING, LAMARCK, and BLAINVILLE rank it as distinct; while DUJARDIN[5] (upon what grounds I cannot discover) ranks it with the *Actinometra pectinata* of JOH. MÜLLER. It is impossible to say with certainty whether the *Decacnemos crocea zaffarana Neapolitanorum* of LINCK, the δεκαδασυακτινοειδῆς of FABIUS COLUMNA, is anything else than a larger form of the same, the description given of it not being sufficiently minute to enable its specific characters to be positively determined; and it may not improbably be the *Antedon Milleri* of NORMAN and WYVILLE THOMSON. With Professor EDWARD FORBES, also, I consider both the *Asterias bifida* and the *Asterias decacnemos* of PENNANT[6], and the *Asterias pectinata* of ADAMS[7] to belong to the same specific type, since their descriptions and figures do not accord with the characters of either of the other British *Comatulæ*: by LAMARCK, however, the *Asterias decacnemos* of PENNANT and the *Asterias pectinata* of ADAMS are identified with the *Decacnemos barbata* of LINCK, which he cites as *Comatula barbata*. Our *Antedon rosaceus* is undoubtedly the *Alecto Europæa* of LEACH[8]; and there cannot, I think, be any question of its identity with the *Comatula Mediterranea* of LAMARCK[9]. Under one or other of these two names this type is referred to in the principal Continental Monographs in which it is specially mentioned; the first being used by Professor JOH. MÜLLER in his memoir "Ueber den Bau des *Pentacrinus Caput-*

---

[1] De Stellis Marinis, p. 55, tab. xxxvii. fig. 66.

[2] British Animals, p. 490.

[3] Manuel d'Actinologie, p. 248.

[4] History of British Starfishes, p. 5.

[5] Histoire Naturelle des Zoophytes Echinodermes, p. 210.

[6] British Zoology, vol. iv. pp. 65, 66.

[7] Linnean Transactions, vol. v. p. 10.

[8] Zoological Miscellanies, vol. ii. 1814, p. 62.

[9] Animaux sans Vertèbres, 2nd Ed., tom. iii. p. 210.

Medusæ"[1]; whilst the second is adopted by MECKEL[2], HEUSINGER[3], SARS[4], DUJARDIN[5], and Professor JOH. MÜLLER in his memoir "Ueber die Gattung *Comatula* und ihre Arten"[6]. Professor WYVILLE THOMSON regards the *Comatula fimbriata* of J. S. MILLER[7], which is described under the name *C. Milleri* by Prof. JOH. MÜLLER, as probably identical with the *Antedon Milleri* of which I have already cited his definition (§ 6, *note*); MILLER'S figure and description of it, however, seem to me scarcely sufficient to remove the doubt suggested by its locality (§ 39) whether it is anything else than the variety of *A. rosaceus* which is characterized by the presence of interradial plates. I am disposed to identify our *Antedon rosaceus* with the *Comatula adeonæ* of DELLE CHIAJE[8]. But it must not be confounded either with the *Comatula fimbriata* or with the *C. adeonæ* of LAMARCK, JOH. MÜLLER, and DUJARDIN, or with the *C. rosea* of JOH. MÜLLER and DUJARDIN, which are distinct types. It is probably identical with the *Alecto petasus* of VON DÜBEN[9] and KOREN.

8. The synonymy of our *Antedon rosaceus*, therefore, I consider to be as follows:—

Stella decacnemos rosacea, LINCK.
 ? *Stella decacnemos barbata*, LINCK.
Asterias bifida, PENNANT.
Asterias decacnemos, PENNANT.
Asterias pectinata, ADAMS.
Alecto Europæa, LEACH, followed by JOH. MÜLLER.
Comatula Mediterranea, LAMARCK, followed by MECKEL, HEUSINGER, SARS, DUJARDIN, and JOH. MÜLLER.
 ? *Comatula barbata*, LAMARCK, followed by FLEMING.
 ? *Comatula fimbriata*, J. S. MILLER.
Comatula rosacea, FLEMING, BLAINVILLE, and EDWARD FORBES.
Comatula decacnemos, J. V. THOMPSON.
 ? *Comatula adeonæ*, DELLE CHIAJE.
 ? *Comatula Milleri*, JOH. MÜLLER.
Alecto petasus, VON DÜBEN and KOREN.
Antedon decameros, GRAY.

The young pedunculate form of *Antedon rosaceus*, moreover, received from its discoverer, Mr. J. V. THOMPSON, the designation *Pentacrinus Europæus*, and from BLAINVILLE that of *Phytocrinus Europæus*; whilst FLEMING proposed for it the designation *Hibernula*.

---

[1] Abhandl. der Königl. Akad. der Wissenschaften zu Berlin, 1843, p. 177.

[2] Archiv für Physiologie, 1823, p. 470.

[3] MECKEL'S Archiv, 1826, p. 317; and HEUSINGER'S Zeitschrift für organ. Physiol., Bd. III. p. 366.

[4] Beskrivelser og Jagttagelser, &c. Bergen, 1835.

[5] L'Institut, 1835, p. 268; and Hist. Nat. des Echinodermes, *Paris*, 1862.

[6] Abhandl. der Königl. Akad. der Wissenschaften zu Berlin, 1847.

[7] Natural History of Crinoidea, *Bristol*, 1821, p. 132.

[8] Animali senza Vertebre del regno di Napoli.

[9] "Ofversigt af Skandinaviens Echinodermer," in Königl. Vetensk. Akad. Handl. Stockholm, 1844.

HABITS.

9. The usual *habitat* of *Antedon rosaceus* appears to be water of from ten to twenty fathoms' depth; though it is found sometimes in shallower, and sometimes in deeper water. My experience agrees with that of Professor E. FORBES, that the largest specimens are obtained from deep water. The animals are generally brought up by the dredge either actually clinging to Sea-weeds (usually *Laminaria*) or to Zoophytes or Polyzoa, or in such association with them as suggests the idea that their detachment has been effected in the act of dredging. For reasons I shall presently give, I cannot by any means assent to the statement of Mr. J. V. THOMPSON[1], that "this curious Star-fish is an animal not only free, but leading the most vagrant life of any of the tribe with which it has been hitherto associated by naturalists,—at one time crawling about amongst submarine plants, at others floating to and fro, adhering to thin fragments by means of its dorsal claspers, or even swimming about after the manner of the Medusæ." It is quite true that, as stated by Mr. J. V. THOMPSON, and confirmed by Professor EDWARD FORBES, an *Antedon* placed freely in water will swim with considerable activity, moving back foremost by advancing five arms at a time, and then the alternate five; in fact I do not know any animal of which the movements are more graceful than those of the "feather-star" (as Professor EDWARD FORBES appropriately called it). But I am quite satisfied from repeated observations that these movements are not habitual to the animal, and are to be regarded only in the light of a restless search after a new attachment, being kept up no longer than is requisite for obtaining this. If an *Antedon* be placed in a large basin of sea-water, having smooth sides and not containing any object of which its dorsal cirrhi can lay hold, the swimming action may continue (with occasional intermissions) for several hours. But if a rough angular stone, a Sea-weed, a Zoophyte, a cluster of Serpulæ, or anything to which its dorsal cirrhi can attach themselves (Plate XXXI.) be placed in the basin, the *Antedon* settles itself upon this, and if the attachment proves suitable, the creature seldom changes it. I have kept a number of *Antedons*, without any other animals, in the same Vivarium for several weeks together; and I have observed that the places of individuals which I could distinguish by some peculiarity of colour, were scarcely at all altered during the whole period,—the amount of change, in fact, being little more than would have been exhibited by an equal number of *Actiniæ*. One fine specimen I particularly noted as having firmly attached itself by the grasp of its dorsal cirrhi to the tube of a Serpula; and this it did not let go during the whole time of its captivity.

10. Thus, as regards the ordinary fixedness of its position, the condition of the adult *Antedon* only differs from that of its *Pentacrinoid larva* in this; that whereas the latter necessarily remains fixed to the spot to which the base of its pedicle was originally attached, the former can quit its hold when its attachment is no longer suitable to its requirements, and can move from place to place in search of another. How intimate, moreover, is the functional relation between the dorsal cirrhi of the adult *Antedon*, and the stem of its Pentacrinoid larva, further appears from the fact that the cirrhi only

---

[1] Edinb. New Philos. Journal, vol. xx. (1835–36) p. 296.

make their appearance in the latter part of the Pentacrinoid stage (as will be seen by a comparison of figs. A, B, C, D, E in Plate XXXIX. fig. 1), in preparation for that detachment of the "summit" from the stem, which thenceforth changes the condition of the animal from the fixed to the free. Notwithstanding that change, the life of the adult *Antedon* is habitually passed (I feel justified in asserting) so nearly in the same degree of fixedness as that of its Pentacrinoid larva, that it may almost equally be regarded as representing the life of the typical CRINOIDEA. If the creature ever quits its attachment, save on account of the unsuitableness of its position, it is probably during the period of sexual activity, at which it seems more frequently errant than at any other stage of its life except the earliest.

11. In regard to the ordinary condition of the Arms, there is much the same variety as is seen among *Actiniæ* with respect to the expansion of their tentacles. Sometimes the arms and their pinnæ are stretched out quite straight to their full length, and almost entirely in the same plane, so as to present an appearance of rigidity; whilst sometimes, still remaining fully extended, they are more or less closed together, so as to give to their whole expanse the shape of a funnel more or less deep, with the central disk at its bottom. More commonly, however, some of the arms curve either obliquely or towards the ventral surface; and this ventral curvature may be so great that the arm forms a spiral which reminds the observer of the unfolding frond of a Fern. Occasionally all the arms are seen to be thus coiled, so that the diameter of the animal is reduced to not more than one-third of that which it has when the arms are fully extended. In no instance have I ever seen the arms more than slightly curved in the dorsal direction; a peculiarity which will be readily accounted for when we examine the structure of their skeleton in detail.

12. Whatever may be the purpose of the habitual expansion of the Arms, I feel quite justified in asserting that it is *not* (as stated by several Authors whom I have cited in my historical summary) the prehension of food. I have continually watched the results of the contact of small animals (as Annelids, or Entomostracan and other small Crustacea) with the arms; and have never yet seen the smallest attempt on the part of the animal to seize them as prey. Moreover, the tubular tentacula with which the arms are so abundantly furnished have not in the smallest degree that adhesive power which is possessed by the "feet" of the ECHINIDA and ASTERIADA; so that they are quite incapable of assisting in the act of prehension, which must be accomplished, if at all, either by the coiling-up of a single arm, or by the folding-together of all the arms. Now I have never seen such coiling-up of an arm as could bring an object that might be included in it into the near neighbourhood of the mouth; nor have I seen the contact of small animals with a single arm produce any movement of other arms towards the spot, such as takes place in the prehensile apparatus of other animals. Moreover, any object that could be grasped either by the coiling of one arm, or by the consentaneous closure of all the arms together upon it, must be far too large to be received into the mouth, which is of small size, and is not distensible like that of the ASTERIADA.

13. A special function was assigned by LAMARCK to what he terms the "rayons simples inférieures," which, as he correctly states, are nothing else than the basal pinnules of the principal arms, "qui sont allongées et abaissées en dessous." He says that these "rayons simples" serve to bring to the mouth the prey which has been captured by the "grands rayons pinnés." This assertion I cannot but consider to be purely hypothetical. It will be shown in the Second Part of this Memoir that there are such peculiarities of structure and disposition on the part of these basal pinnules—which are much longer than the rest, and habitually arch over the central disk (Plate XXXI. A)—as indicate a speciality of function; but I feel confident that the function assigned by LAMARCK cannot be the true one. For not only have I failed to perceive, after long continued observation and repeated experiments, any such *movements* of these pinnæ as would indicate a prehensile action, but I have found reason to suspect their function to be that of *sensorially* protecting the soft parts which occupy the ventral surface of the disk, and of preventing unsuitably large particles from being drawn in by the oral current. For if the *ordinary* pinnules of any arm be irritated by the contact of a rod, such irritation merely produces a languid wavy motion of the arm thus acted-on, which may extend itself to others if the irritation be repeated or prolonged. But if the rod be made to irritate the long *basal* pinnules, all the arms (if the animal be in full vigour) immediately close together, with an energy and consentaneousness that are seen in no other movement.

14. It was affirmed by M. DUJARDIN (l'Institut, No. 119, p. 268) that the arms are used for the acquisition of food in a manner altogether dissimilar to ordinary prehension; for recognizing the fact that the alimentary particles must be of small size, he supposed that any such, falling on the ambulacral (?) furrows of the arms or pinnæ, are transmitted downwards along those furrows to the mouth wherein they all terminate, by the mechanical action of the digitate papillæ which fringe their borders. This doctrine he appears to have subsequently abandoned; since in his last account of this type (Hist. Nat. des Echinodermes, p. 194) he affirms that the transmission of alimentary particles along the ambulacral (?) furrows is the result of the action of cilia with which their surface is clothed. Although I have not myself succeeded in distinguishing cilia on the surface which forms the floor of these furrows, yet I have distinctly seen such a rapid passage of minute particles along their groove, as I could not account for in any other mode, and am therefore disposed to believe in their existence. Such a powerful indraught, moreover, must be produced about the region of the mouth, by the action of the large cilia which (as I shall hereafter describe) fringe various parts of the internal wall of the alimentary canal, as would materially aid in the transmission of minute particles along those portions of the ambulacral (?) furrows which immediately lead towards it; and it is, I feel satisfied, by the conjoint agency of these two moving powers that the alimentation of *Antedon* is ordinarily effected. In the very numerous specimens from Arran the contents of whose digestive cavity I have examined, I have never found any other than microscopic organisms; and the abundance of the horny rays of

Peridinium tripos (Ehr.) has made it evident that in this locality that Infusorium was one of the principal articles of its food. But in *Antedons* from other localities, I have found a more miscellaneous assemblage of alimentary particles; the most common recognizable forms being the horny casings of Entomostraca or of the larvæ of higher Crustacea. It is not a little curious that in the specimens of *Antedon* which, through the kindness of Mr. C. Stewart, I have received from Plymouth Sound, the alimentary canal is frequently almost choked up by the body of a Suctorial Crustacean with its egg-masses. As this is far too large and powerful an animal to have been drawn into the mouth by the ciliary current as an article of food, and as its body rarely shows any indication of having been acted on by the digestive power of the *Antedon*, I am disposed to think that it has been introduced either as an egg or as a larva, and has undergone its development parasitically where it is found.

15. There is one point in the habits of *Antedon* which must be regarded as of considerable importance in the determination of the office of that vast aggregate of tubular tentacula which is borne by the pinnated arms; namely, its close dependence, for the maintenance of its life, upon pure well-aërated water. The contrast in this respect between *Antedon* and members of the Order Ophiurida inhabiting the very same localities and brought up from the same depths, is extremely striking. For the "sand-stars" and "brittle-stars" are among the most hardy of the Echinoderms, maintaining their activity in the Vivarium under circumstances fatal to the life of most others of its ordinary inhabitants; and I have seen them moving about for half an hour in dilute glycerine, immersion in which soon kills ordinary Starfishes. On the other hand, *Antedons* are among the first to die, when kept with other animals in a Vivarium; and although I was at first inclined to attribute this to the circumstance of their habitually living under a much greater pressure of water than the littoral animals with which they are associated in such artificial collections, yet I soon came to be satisfied that the real explanation was to be found in their inability to sustain any deficiency in the purity of the medium they inhabit. For by placing them by themselves, in small numbers, in an adequate supply of water, and by frequently renewing this, I have succeeded in keeping the same specimens for several weeks together; and the deficiency of vigour which they showed at the end of that time,—manifested in a general flaccidity of the arms, and in a disposition to the casting-off of portions of them,—appeared quite explicable by the insufficiency of their food-supply, made evident by the progressive shrinking of the visceral mass, the ventral surface of which came at last to be concave instead of protuberant. Moreover it happened on several occasions that if a dozen specimens of *Antedon* were thrown at night into a large basin of water, and were left without any means of attachment, they were all found dead in the morning, conglomerated at the bottom of the basin, clinging to each other with their dorsal cirrhi, and having their arms intertwined in such a manner as to suggest the idea that they had died of the Asphyxia produced by overcrowding, after exhausting themselves in efforts to find a suitable attachment. Whilst if, in a basin of the same size and containing the same quantity of water, there

were placed, with a like assemblage of specimens, a sufficient number of rough stones to afford them all a basis of attachment, they would be all found in the morning in a state of full expansion, with every appearance of health and vigour. Hence I feel justified in concluding that in these animals the Respiratory function can only be effectually performed in a pure well-aërated medium, and that the free exposure of the arms to that medium is no less required. I may add, further, that the intermixture of a small proportion either of fresh-water or of glycerine with the sea-water in which *Antedons* are immersed, is very speedily fatal to them.—It will be shown in the Second Part of this Memoir that, besides the so-called "ambulacral" canal with its tentacular extensions, each Arm and each Pinnule contains an afferent and an efferent canal, in which the nutritive fluid is exposed to the aërating influence of the surrounding medium. And that this Branchial function is shared by the Tentacular apparatus also, would appear alike from the negation already given to its supposed prehensile activity, and from its own structure and relations, as will be fully shown hereafter. Such a double provision for the function of Respiration has been shown by M. DE QUATREFAGES to be very common among the ANNELIDA.

16. From the foregoing observations and the reasonings based upon them, we seem justified in regarding the following as probable conclusions:—

1. That *Antedon*, so far from being an active free-swimming animal, has the same fixed habit in its mature attached as in its earlier unattached condition; so that in regard to its general manner of life, it is not less entitled in the later than in the earlier stage of its existence, to rank as a type of the Crinoids generally.

2. That neither the Arms and their ordinary Pinnules, nor those elongated basal Pinnules which arch over the central disk, have any prehensile action, or any direct concern in obtaining supplies of food.

3. That the ordinary Pinnules are specially related to the function of *respiration*, in virtue alike of their proper Branchial canals, and of the ambulacral canals and the tubular tentacula with which they are furnished.

4. That the elongated basal Pinnules, in which the tubular tentacula are wanting, are rather related to the function of *sensorial protection* than to that of prehension.

IV.—STRUCTURE OF THE SKELETON.

1. *Of the Skeleton generally, with its Ligaments and Muscles.*

17. The component pieces of which the Skeleton of Antedon is made up, alike in its adult condition and in every previous phase of its existence, present a remarkable accordance with each other in elementary structure; consisting throughout of that calcareous reticulation[1]—formed by the calcification of an animal basis that seems

---

[1] This reticulation appears to have been first noticed by Professor J. MÜLLER in 1841 (Über den Bau des *Pentacrinus*) as constituting the skeleton of the recent *Pentacrinus* of the Antilles. It was more fully described by Professor VALENTIN in 1842 (Anatomie du genre *Echinus*) as presenting itself in the shell and spines of that

nothing else than non-differentiated sarcode—which I have shown (*loc. cit.*) to be the essential constituent of the skeleton in every type of the Class ECHINODERMATA. The character of this reticulation is best seen either in very thin sections of any portion of the skeleton (Plate XXXV.), or in that curiously-inflected cribriform lamina (Plate XXXIII. figs. 9–11) which I have termed the "rosette" (§ 35). This is the only part of the skeleton of the adult *Antedon* in which the reticulation lies all in one plane; but, as Professor WYVILLE THOMSON has already shown, even its most solid portions, such as the First Radials, make their first appearance in the same form of cribriform lamellæ (Plate XLI. fig. 1); and whilst these lamellæ increase in superficial dimensions by the extension of the reticulation from their margins, they are augmented in thickness also by an extension of the reticulation from their inner surfaces into the animal basis in which they are imbedded.—When a portion of the skeleton, either from a fresh or from a spirit-specimen, is subjected to the action of dilute nitric or hydrochloric acid, by which the calcareous network is dissolved away, a continuous film of pellucid sarcodic substance is left, presenting no other trace of structure than in being studded at regular intervals with minute granular spots (Plate XLIII. fig. 1). The precise accordance of these spots, both in size and distance, with the meshes of the reticulation, leaves little room for doubt that whilst the pellucid sarcodic substance is the basis of the calcified network itself, the granular glomeruli occupy its interspaces. From the behaviour of this basis-substance with reagents, it seems to correspond closely with the *plasma* of the higher animals and with the *sarcode* of the lower; the pellucid substance being apparently albuminoid in its nature, whilst the granular spots are partly composed of oil-molecules.

18. The pieces of the skeleton are held together by *Ligaments*, which consist of minute well-defined fibres bearing a strong resemblance in aspect to those of the Yellow Elastic substance, but not (like them) capable of resisting the action of strong acetic acid. The diameter of these fibres (Plate XLIII. figs. 3, 3A) does not exceed $\frac{1}{15000}$ of an inch; they usually run straight and parallel, but sometimes cross each other obliquely. Their attachment to the pieces of the skeleton which they connect is peculiarly firm; and this firmness is found to depend, when we examine portions of the skeleton that have been subjected to decalcification, on the passage of the fibres into the basis-substance of the skeleton itself (§ 27); much as the fibres of ligaments attached to bones are continuous with their fibroid basis, or as the fibres of tendons attached to cartilages pass into their intercellular substance. From the position and action of the ligaments connecting the pieces of the skeleton of *Antedon*, I think it is clear that some of them are simply *inter-articular*, having for their function to tie these pieces together, but allowing a certain

---

genus. And having myself independently discovered it, I was at the same period engaged in tracing it through all the leading types of the class ECHINODERMATA, fossil as well as recent; the results of which inquiries were made known in the Annals of Natural History, vol. xii. (1843) p. 377; and more fully in the Reports of the British Association for the year 1847.

freedom of movement between them; whilst others are decidedly *elastic*, their action being to antagonize muscles, as in many other well-known cases among Vertebrate and Invertebrate animals. Where a firm union is required, without power of movement between one segment and another,—as we shall find to be the case in regard to the pieces which form the basis of the calyx,—there is no ligamentous connexion, but simply an adhesion of expanded surfaces, closely fitted to each other, and held together by the continuity of their sarcodic basis-substance.

19. The segments of the Arms and of their lateral pinnæ, and to a certain extent those of the Rays which bear them, are made to move one upon another by a highly-developed *Muscular* apparatus. This consists of fibres (Plate XLIII. fig. 4) which resemble those of the ordinary muscles of *Terebratulæ*[1] in their general appearance and their want of mutual cohesion. They are cylindrical, or somewhat flattened, and show no trace whatever of transverse striation (Plate XLIII. fig. 4, A). Their diameter is about $\frac{1}{12000}$ of an inch; and I have not been able to resolve them into more minute elements. Interspersed among them are numerous spheroidal corpuscles ranging in diameter from about $\frac{1}{10000}$ to $\frac{1}{6000}$ of an inch: similar corpuscles of hemispherical or elongated form are frequently to be seen adhering to the edges of the fibres by their flattened faces (*a*, *b*); and sometimes elongated corpuscles are observable, over which the border of the fibre seems continuous (*c*). What is the Histological import of these corpuscles, does not seem very clear. I do not find that either they or the fibres are specially affected by the ordinary reagents. The fibres expand a little at their terminations (fig. 4, *a*), so as to come into closer union than elsewhere; and these expanded terminations are simply applied to the surfaces of the calcareous segments to which they are attached, not passing into their substance; so that the muscular bundles are easily torn away *en masse*, leaving no such roughness behind as when a ligamentous connexion is similarly treated. From the entire absence of anything like Sarcolemma or Connective tissue, the fibres are very easily isolated from each other; and there is no difficulty in tracing the same individual fibres from one point of attachment to the other through the whole length of the muscular bundle, which is sometimes as much as $\frac{1}{42}$ of an inch. The entire absence of any other component in the substance of these Muscles is a point of no little interest. After careful and repeated examination of them, I feel justified in stating that they show no trace either of Blood-vessels or Nerves; yet the evidence already given (§§ 9, 13) from observation of the habits of the living *Antedon*, shows that in energy and rapidity of muscular action it surpasses every other known animal of its class. When we come to study the Nutritive apparatus, we shall find that although no Blood-vessels pass into the *substance* of the Muscular bundles, their *surface* forms the floor of a canal filled with nutritive fluid, for the aëration of which there is a special provision in the wide expansion of the Arms. The mode in which Nervous influence is conveyed to them is a problem of greater difficulty. It will be shown in the Second Part of this Memoir,

---

[1] See Mr. HANCOCK's Memoir "On the Anatomy of the *Brachiopoda*," in Philosophical Transactions for 1858, p. 804.

that the cord which traverses the length of the Arms between the canal just mentioned and another canal that overlies it, and which was regarded by Professor Müller as a nerve, really belongs to the Reproductive apparatus. But it will also be shown that a regular system of branching fibres proceeding from the solid cord (described by Professor Müller as a vessel) that traverses the axial canal of each calcareous segment of the Rays nd Arms (§§ 34, 45) is traceable on the extremities of the muscular bundles; and reasons will be given for regarding these fibres as probably having the function of Nerves, though not exhibiting their characteristic structure.

2. *Of the Component Pieces of the Skeleton.*

20. In accordance with the nomenclature now generally adopted in describing the Crinoidea, I shall distinguish the pieces of the skeleton as belonging (1) to the *Stem*, (2) to the *Calyx*, and (3) to the *Arms*.

21. *Stem.*—As the body of *Antedon*, although attached by a stalk during the Crinoidal stage of its existence, becomes free by separation from this as it approaches maturity, its skeleton might not be expected to include any representative of the Crinoidal stem. Such a representative, however, unquestionably exists in the central protuberant plate, to the convex surface of which the Dorsal Cirrhi are attached, whilst its ventral surface gives support to the First Radials. The real nature of this plate was discerned by the acute Naturalist to whom we owe our first scientific acquaintance with the Crinoid type; the following description being given of it by Mr. J. S. Miller (Crinoidea, p. 129):—"At the base of the subglobose body of the *Comatulæ* exists a pentagonal unperforated plate, slightly convex externally, and concave on the inside. *It is analogous in situation to the first columnar joint of the Crinoidea*; but as it is not required to transmit the passage to the alimentary canal (no prolongation of the column existing in this animal), it is without central perforation"[1]. The true homology of this central plate was also dis-

---

[1] The above description must be taken in connexion with that of the "Pelvis" in the succeeding paragraph. "On the margin of the pentagonal plate rests an annular plate resembling the rim of a basin, and forming with the former a basin-like cavity, which appears to occupy the place of the pelvis of the Pentacrinite. At the upper edge this pelvis-like plate is pentagonal, having between each of the angles a horseshoe-like impression for the insertion of the first costal joint. Externally numerous auxiliary side arms [the 'dorsal cirrhi' of Lamarck and most succeeding authors] proceed from the *pelvis-like* plate, which, when they are broken off or removed, show the exterior surface of the plate marked with concave impressions (the points of their insertion), each surrounded by a hexagonal rim more or less perfect, according as their situation is near the central or the marginal circumference of the plate." It would hence appear that Miller was led by his idea of the homologies of the centro-dorsal plate to regard it as composed of two pieces, one forming the bottom of the basin, the other its sides and rim. This, however, is certainly not the case; since not only does the most careful examination of the plate in its mature form show no trace whatever of such separation, but its unity is clearly shown by the history of its development.—The latter part of the above-cited description of the "pentagonal plate" is based on the idea that the canal which passes down the centre of the Crinoidal stem lodges a continuation of the Digestive cavity. This has been shown by Professor J. Müller to be quite untrue as regards the recent *Pentacrinus Caput-Medusæ*; and I shall hereafter show that nothing of the kind obtains in the Pentacrinoid stage of *Comatula*. At a time when so little was known of the Anatomy of the Echinoderm type,

cerned by Professor J. Müller, who was led by his comparison of the component pieces of the calyx of *Comatula* with those of the calyx of *Pentacrinus Caput-Medusæ* to perceive that the "centro-dorsal" or "knopf" of the former is the representative of the highest joint of the stem of the latter; the annulus formed by the adhesion of the First Radials resting in each case upon its upper surface. The correctness of this view is placed beyond all doubt by the study of the development of this "centro-dorsal plate:" for, as I shall show in more detail hereafter (Sect. V.), this plate first presents itself in a form which nowise differentiates it from the other joints of the cylindrical stem; but begins to take on an extraordinary increase in a peripheral direction at the time when the dorsal cirrhi first sprout forth, and thenceforward remains in closer connexion with the Calyx than with the rest of the Stem, from which it separates itself so soon as the dorsal cirrhi are sufficiently developed to serve for the attachment of the animal.

22. The *Centro-dorsal* plate[1] has the form of a shallow basin, with thick walls, and lip turned inwards instead of outwards (Plate XXXIII. figs. 4, 5, 6). Its outer margin, without departing much from the circular form, approaches the pentagonal sufficiently to justify the designation given to it by J. S. Miller; and the margin of its inverted rim, forming the boundary of the opening into its cavity, is also slightly pentagonal. The diameter of this plate, in a full-grown *Antedon*, is about ·16 inch; and its whole depth ·07 inch, of which about half is the depth of its cavity, and the other half the thickness of its bottom. The thickness of the peripheral portion of its wall, however, to which alone the dorsal cirrhi are attached, is about twice that of the deepest part of the basin; as is shown in the vertical section represented in Plate XXXV. fig. 2. The central portion of the convex dorsal surface, by which the centro-dorsal plate was originally articulated to the joint of the stem next beneath, is nearly flat, and shows no peculiarity. But the entire peripheral portion is marked out into distinct sockets for the articulation of the dorsal cirrhi. These sockets are more or less circular depressions, separated by intervening ridges; and from the bottom of each depression there rises a tubercular elevation having a minute perforation in its centre. About *forty* sockets may usually be counted in a full-grown specimen, disposed for the most part in two rows, one alternating with the other (Plate XXXIII. fig. 5). Of these sockets, however, there are usually some to which no cirrhi are attached; these, which are generally the nearest to the centre of the disk, are distinguished by the partial filling-up of their cavity, so that the intervening ridges and the central tubercles become less conspicuous, and by the absence of perforations in the latter. The meaning of this difference will become obvious, when we follow out the development of the Centro-dorsal plate and its appendages (§§ 75, 86–88), and mark the transference of the prehensile

---

Miller's hypothesis was not so untenable as we have since come to regard it; but the unhesitating tone in which the penetration of the stem by the Alimentary Canal is spoken of throughout Miller's Treatise, should furnish a warning against any such assumption.

[1] The "centro-dorsal piece" of many authors is compounded of the true *centro-dorsal plate* and of the *pentagonal base* or circlet of *first radials* which closely adhere to it and to each other (§§ 23, 31).

apparatus from the central to the peripheral portion of its convex surface, which is effected by the successional development of new cirrhi at the growing margin, whilst those which were originally implanted around the surface of articulation with the next joint of the stem appear to be cast off.

23. The upper or ventral surface of the Centro-dorsal plate (Plate XXXIII. fig. 6) which is formed principally by the thick wall of the basin, but partly also by its inturned lip, is nearly flat; being slightly elevated between the angles of its external and its internal pentagons, and somewhat depressed in the intervening spaces. The elevations correspond with the lines of junction of the First Radials that rest upon it; and the depressions with the convexities of their dorsal surfaces (fig. 2). Its adhesion to the under side of the annulus formed by the First Radials is so close, that the line of junction is not readily distinguishable in a vertical section of the "centro-dorsal piece" compounded of both (Plate XXXV. fig. 1, *a*, *a*); and it is generally more easy to break away the centro-dorsal plate piecemeal, than to detach it as a whole from the annulus of first radials,—unless the composite piece has been boiled in a solution of caustic alkali, which dissolves the organic substance whereby they are cemented together. Round the margins of the internal pentagon, we commonly find five shallow depressions (Plate XXXIII. fig. 6, *a*, *a*) which correspond with the extremities of the elongated spout-like processes of the "rosette" (§ 35); these, however, are seldom as strongly marked as in the figure, and are sometimes wanting altogether.

24. The internal surface of the wall that bounds the cavity of the basin is marked by minute punctations (Plate XXXIII. fig. 6), which are the internal orifices of canals that proceed from the interior cavity of the Centro-dorsal plate to the centres of the tubercles in the sockets on its convex or dorsal surface. The course of these canals, whose diameter averages $\frac{1}{500}$ of an inch, is shown in sections of the basin taken either perpendicular or parallel to its upper flattened surface (Plate XXXV. figs. 1, 4, *b*, *b*). In such sections, when sufficiently magnified, it is also to be observed that the calcareous network which forms the basis of each socket is more solid than that of the general substance of the plate; its meshes being closer, and arranged with a regularity not observed elsewhere (fig. 4, *c*, *c*). This is conformable to what is seen in the test and spines of *Echinus*; the articular tubercles of the former and the basal cups of the latter being composed of a peculiarly close calcareous reticulation[1]. When this centro-dorsal plate is decalcified, the animal basis is found particularly firm at these spots, each socket having a membranous disk of its own, which is traversed by very fine ligamentous fibres having a radiating arrangement; and by the convergence of these fibres is formed the interarticular ligament which binds the first joint of the dorsal cirrhus to its articular socket.

25. *Dorsal Cirrhi.*—The dorsal surface of the calyx of *Antedon* is ordinarily in great degree concealed by the cluster of Dorsal Cirrhi, which radiate from the convex surface of the centro-dorsal plate (Plate XXXII. fig. 4), and which extend, when straightened

---

[1] See Professor VALENTIN's Monograph 'Anatomie du genre *Echinus*,' pp. 20, 31, figs. 16, 17, 36, 38.—My own preparations of these structures fully bear out Professor VALENTIN's descriptions.

out or nearly so, considerably beyond the margin of the disk. These appendages, for which it seems to me that the designation given by LAMARCK and adopted by DUJARDIN is the most appropriate, were termed by J. S. MILLER "auxiliary side arms," by BLAINVILLE "rayons auxiliaires," by Professor J. MÜLLER "ranken," and by Professor EDWARD FORBES "filaments, jointed appendages, or simple arms." Any name which indicates a resemblance between these cirrhi and the Rays or Arms belonging to the *calyx*, is most inappropriate; since the two sets of organs have no other point of resemblance than that which consists in the articulated structure of their skeleton, whilst they differ *in toto* as regards both their homological relations and their functional uses. The designations respectively applied to them by J. S. MILLER and by BLAINVILLE were so far correct, as indicating their homology with those appendages of the stem in *Pentacrinus* which these authors distinguished by the same terms; and it is expressly stated by the former that "these arms, the formation of their joints, and their hook-like termination, resemble in every particular those of *Pentacrinus Caput-Medusæ*, only that they are much shorter, and formed of a less number of joints." That the "dorsal cirrhi" of *Antedon* have no other function than that of mechanically fixing the animal, appears alike from the extreme simplicity of their structure (which presents not the smallest trace of the complex apparatus that is extended throughout the whole of the true brachial appendages), and from observation of the animal in its living condition, as I have already shown in the description of its habits (§§ 9, 10).

26. The *number* of the Dorsal Cirrhi in *Antedon rosaceus* is by no means constant, nor is their size uniform. It is by no means uncommon to find, even on the largest specimens, one, two, three, and sometimes more of these organs in a very rudimental condition; such being usually interposed between the larger ones at the extreme circumference of the Centro-dorsal plate. In order to ascertain the range of variation in this character (to which some systematists attach considerable importance in the discrimination of species), I have carefully removed and laid upon separate tablets the entire clusters of cirrhi possessed by *twelve* Arran specimens, which, although differing in size, all presented every appearance of maturity; and I find the respective numbers of these organs to be as follows:—

I.	21,	of which	3	were rudimental.	VII.	27,	of which	3	were rudimental.
II.	22,	„	4	„	VIII.	29,	„	2	„
III.	25,	„	3	„	IX.	29,	„	0	„
IV.	25,	„	7	„	X.	30,	„	2	„
V.	25,	„	3	„	XI.	32,	„	4	„
VI.	27,	„	3	„	XII.	32,	„	1	„

Thus it appears that Professor EDWARD FORBES was not far wrong in stating the number of these organs to be from *twenty* to *thirty*[1]. I cannot, however, by any means agree

---

[1] History of British Starfishes, p. 7. The number of cirrhi in *Comatula Mediterranea* is stated by LAMARCK at 30, by Professor JOH. MÜLLER at 30–40, and by DUJARDIN at 20–26.—I have lately had the opportunity, through the kindness of MR. J. GWYN JEFFREYS, of examining a variety of *Antedon rosaceus* from the coast of

with him in the following statement (*op. cit.*, p. 7): "These filaments are not all alike; there are two kinds of them. The larger have fourteen joints, and a small thick, blunt, curved claw, which is smaller than the joints, and has a horny lustre: the smaller filaments have eighteen rough joints, and an almost straight claw, which is larger than the joints preceding it." I shall presently show that the first-named form is that of the fully developed cirrhus, whilst the latter (save as to the number of joints) is that of the same organ in an earlier stage of its development; and that occasionally (though rarely) the rudimental form is retained with an increase in the number of joints beyond the average. In each of *eleven* out of the *twelve* specimens, in which I have examined the cirrhi with great care, I have found the predominant number of segments, excluding the one which bears the claw, to be 15; but in at least one-third of the cirrhi in each of these specimens (excluding those which retained their rudimental characters) the number of segments is below that standard, ranging from 14 to 10, and in a few instances to 9. In the single exceptional specimen, the predominant number of segments was 16, and *one* cirrhus had 17 (besides the claw); and this number I have never found exceeded, though the whole number of cirrhi whose joints I have counted exceeds 300. In *two* cirrhi retaining the rudimental form, I have counted 17 segments besides the claw; but I have never found this number exceeded[1].

27. The typical form of the Dorsal Cirrhi is represented in Plate XXXII. fig. 5, *a*; in which we notice (1) that the cirrhus is curved along a great part of its length in the same direction as its terminal claw, the distinction being thus marked between its convex or oral and its concave or aboral border; (2) that the basal segments are short, their diameter considerably exceeding their length, and are cylindrical, or nearly so; (3) that there is a progressive increase both in the length and in the diameter of the segments as far as the 11th joint, this increase being at first so much more rapid in length than in diameter that the 5th, 6th, 7th, and 8th segments are considerably longer than they are broad, approaching the proportion of 3 : 2[2], with some degree of lateral compression; (4) that beyond the 11th joint the length of the segments again diminishes, their diameter remaining nearly the same; (5) that the last segment has attached to it by simple suture a strong, sharp claw, and is itself prolonged at the base of this, on its aboral margin, into a short pointed opposing process[3]. Between the segments is

---

Ross-shire, one specimen of which possesses 42 dorsal cirrhi of which 7 are rudimental, and another 46 of which 8 are rudimental.

[1] The number of joints in the cirrhi of *Comatula Mediterranea* is stated by Professor J. Müller to be 18–20, and by Dujardin to be about 20.

[2] I am particular in the statement of these proportions, because they have been employed on insufficient grounds (as I believe) by Professor Wyville Thomson as a character of specific distinction between *A. rosaceus* and *A. Milleri*.

[3] This process, as I shall presently show, is almost always wanting in cirrhi which have not attained their full development; and as it is not unfrequently absent in such as show no other characters of immaturity, I cannot agree with Professor Wyville Thomson (*loc. cit.*) in regarding the possession of this opposing process as a valid specific character of *A. rosaceus*.

interposed a ligamentous (not muscular) substance; this is seen in the basal joints to be as thick on the oral side as it is on the aboral; but as we advance towards the middle of the cirrhus, the thickness of the interarticular substance is seen to be much greater on the aboral side, the form of the segments being so modified as to admit of considerable flexure in that direction, whereby the prehensile power of the claw is much increased. When a cirrhus is subjected to decalcification, it is found that this interarticular substance corresponds with the general sarcodic basis of the skeleton in every particular, save in the great abundance and regular distribution of its fibrous component. The fibres can be distinctly traced passing straight and direct between the articular surfaces (Plate XLIII. fig. 5), not terminating there, however, as do the muscular fibres (§ 19), but becoming incorporated with the basis-substance of the calcified segments. And it seems clear from the history of the development of these organs, that the basis-substance of the calcified segments and the interarticular substance which connects them, are originally similar; but that whilst the former is altered by the deposit of its calcareous reticulation, the latter is changed by the augmentation of its fibrous component. The connexion of the basal segment with the socket of the centro-dorsal plate to which it is articulated, is effected by precisely the same kind of ligamentous substance (§ 24).

28. When the segments are separated by boiling in a solution of potass, and their opposed faces are examined (Plate XXXIII. fig. 8), it is seen that each is perforated by an axial canal of about one-fifth of its diameter, around which is a projecting articular surface; and that on the oral and aboral sides of this projection there are two depressions for the lodgment of the interarticular ligament. In the basal segments (*a*), the canal with its surrounding projection is central, and the oral and aboral depressions are of equal size, or nearly so; but in the terminal segments (*b*) the canal and articular surface are nearer the oral side, and the ligamental depression is both larger and deeper on the aboral. This difference is still better seen in longitudinal sections of these two portions of the cirrhus respectively (Plate XXXV. figs. 2, 3); in which also we observe that the terminal claw is attached to the last segment at *a*, *a*, by a plane surface admitting of no movement, the two being held together by continuity of their animal basis-substance. When a thin portion of such a section is examined with a sufficient magnifying power, the calcareous reticulation is seen, as in other cases (§ 24), to be much closer at the articular surfaces than it is elsewhere; and in the portion of the last segment which is prolonged into the opposing process (fig. 3), the reticulation is covered with a layer of homogeneous shell-substance like that which forms the solid pillars in the spines of the ECHINIDA. Of this substance nearly the whole solid shell of the terminal claw is composed, its interior, however, being occupied by a large cavity which is continuous with the axial canal (*c*, *c*) of the cirrhus, and the inner layer of its wall having the characteristic reticular structure.

29. The Axial Canal which thus runs from the base to the apex of each Cirrhus, is continuous at its base with the canal which passes from the concavity of the Centro-dorsal plate to the summit of each articular tubercle (§ 24). It was supposed by Professor

J. Müller, who first noticed its presence, to be occupied by a nutrient *vessel*, proceeding from an organ contained in the basin-shaped cavity of the Centro-dorsal plate, which he designated as a *heart*, and from which he asserted that similar but much larger vessels pass off into the Radial plates, and thence by bifurcation into the Arms. I am perfectly satisfied, however, that these axial canals are occupied by *cords* of unconsolidated sarcodic substance; and that the central organ from which they proceed is developed out of the original Crinoidal Axis. How far these cords are subservient to the nutrition of the organ, or to the maintenance of its vitality, is a question that will be fully considered when the structure and function of the central organ to which they are related come under review, in the Second Part of this Memoir.

30. Having thus described the structure of the typical Cirrhus and of its component pieces, I have to speak of the cirrhi whose condition departs more or less widely from that type. In almost every specimen of *Antedon* we find cirrhi which do not present all the characters of maturity; and there are very commonly some whose condition is quite rudimental, corresponding to that which will be described in detail when the development of the several pieces of the skeleton is being traced out (§ 66). Such a one, represented at *b* (Plate XXXII. fig. 5), is seen to consist of *eight* minute cylindrical segments, of which the basal is the largest, and of which the terminal is rounded off without any appearance of a claw. At *c* is shown a more advanced stage of the same rudimental form; the segments having increased in length and diameter, but without showing any other change. At *d* we have a cirrhus which still presents the same rudimental form of the segments, but these have increased in number to *ten*, and the last segment carries a small claw; and the same condition is still presented at *e*, though the number of segments has increased to *twelve*. At *f*, however, we not only see an increase in the size and number of the segments, of which there are *sixteen* besides the terminal claw, but there is an incipient bevelling-off of the opposed faces of the segments on their aboral side, which indicates an advance in development towards the mature type; and the basal segments are equalled in diameter by those which follow. It is comparatively rare, however, to find the rudimental form still exhibited by cirrhi which have attained dimensions so considerable; the shaping-out of the segments often taking place when they are still of very small size, and the terminal claw presenting its characteristic form almost from the first. This course of development is seen in the series marked *g*, *h*, *i*, *k*, *l*, *m*;—in which it is to be observed that the basal segments are even from the first of no larger diameter than the rest; that the mature proportions between the length and breadth of the segments are shown at a very early period (*h*); that the bevelling-off of the opposed faces on the aboral side takes place (*i*) when both in number and dimensions the segments are very immature; and that in a cirrhus (*l*) whose length and diameter do not exceed *one-eighth* of the normal standard shown at *a*, all the characters of maturity are presented by the individual segments, even to the development of the opposing process on the penultimate segment. Hence between this and the typical mature cirrhus, the only difference consists in the *number* and *size* of the segments. At *n* is seen

a cirrhus which consists of the typical number of segments, and which presents the general characters of maturity except as regards the form of the claw, but has not attained above three-fifths of the full length; this may obviously have been produced either by a more advanced *development* of the large rudimental form represented at *f*, or by the process of simple *increase* in the small mature form shown at *m*.—The augmentation in the number of segments I believe to be effected by the interposition of new segments at the base, this being the part at which they are of the smallest dimensions and have most the appearance of immaturity. The augmentation in size is produced by addition to every part of the surface of the segment, this being imbedded (so to speak) in the animal basis-substance, into which the calcareous reticulation extends itself from the part previously solidified. It is to the large size of the meshes of that reticulation in the rudimental segments, that the roughness of their surface is due: as they approach maturity, the reticulation formed on the exterior of the old becomes closer, so as to give greater compactness of texture and smoothness of surface; and this is especially the case, as already mentioned, with that which forms the articular faces.

31. *Pentagonal Base of the Calyx*.—When the Centro-dorsal plate has been detached from the rest of the Calyx (which is readily effected by boiling for a short time in a dilute solution of caustic potass), we find the basis of the latter to consist of a pentagonal disk, formed by the close mutual adhesion of the five First Radials. The composition of this disk is obvious enough when we look at the smooth dorsal surface (Plate XXXIII. fig. 2) which was adherent to the margin and inverted lip of the centrodorsal basin; the quinary division being clearly marked out by five radiating sutures. But on its ventral aspect (fig. 3) the sutures are less distinguishable, owing to the peculiar inequality of the surface. The inner portion of the pentagonal base forms a sort of funnel, that slopes inwards to the central space; and the walls of this funnel present an alternation of radiating ridges and furrows, of each of which there are ten. Five of the furrows correspond with the divisions between the component pieces; and of the ridges which bound them, one belongs to each of the two adjacent Radials. Of the other five furrows, one passes along the middle of each of the five Radials; and both the ridges which bound it belong to the same piece. The outer portion of the ventral face of the pentagonal base consists of five surfaces inclining outwards, and marked by peculiar ridges and fossæ which will be better described when the separate pieces of this disk come under view (§ 33). Turning again to the dorsal aspect, we find the central vacuity of the pentagonal disk to be occupied by a single plate of extremely delicate conformation and peculiarly inflected shape (Plate XXXIII. figs. 2, 9); which I do not find to have been noticed by any of those who have previously described *Antedon*, and which, for the sake of facility of reference, I shall term the *Rosette*. I shall hereafter show, however, that it is really a composite structure, formed by the coalescence of outgrowths from the five Basal plates which constituted the primitive foundation of the calyx (§ 59), the original plates having been themselves almost entirely removed by absorption (§ 90). Its peripheral portion is so closely applied to the internal faces of the Radials of

which this pentagonal base is composed, as to seem in absolute continuity with them (Plate XXXV. fig. 1, *f*); whilst its central part also is frequently connected with it by delicate processes, which sometimes sprout forth irregularly from the inner margins of the component pieces of the pentagonal disk, but sometimes form a more regular ingrowth, which considerably contracts the central space on the ventral aspect of the disk (Plate XXXIII. figs. 1, 3), and becomes continuous with an annular projection from the ventral face of the rosette.

32. The Pentagonal Base may be readily separated, after continuous boiling in the potass-solution, into its component First Radials, their mutual adhesion, and their adhesion to the centro-dorsal plate, being due to the interposition of a thin layer of sarcodic substance, continuous with that which occupies the meshwork of their own calcareous reticulation. The extreme fragility of the delicate processes whereby they are severally connected with the "rosette," occasions their detachment from it when they are separated from one another. In the adult condition of *A. rosaceus*, the "rosette" itself is not resolved into distinct pieces by any amount of boiling; although in its immature stage it is readily separable into five component plates (§ 90).—The pieces of which the Pentagonal Base is made up will now be described in detail.

33. *First Radials.*—Each of these pieces has a well-marked triangular form, the apical portion of the triangle, however, being deficient (Plate XXXVI. fig. 1, C, D). We may distinguish its *ventral* and its *dorsal* faces (C, D), the former looking towards the concavity of the calyx, whilst the latter is in contact with the centro-dorsal plate; its *internal* face (B) bordering the central space of the pentagonal disk; its two *lateral* surfaces (B, *i*, *i*) by which it adheres to its fellows; and its *external* face (A), by which it is articulated with the Second Radial. The *ventral* face (C) is divided by two curved ridges (*d*, *d*), bending towards each other along the median line, and there separated by a furrow, into a central and a peripheral portion, the former sloping inwards, so as to contribute to the formation of the central funnel; whilst the latter slopes outwards, so as in fact to become part of the external face of the plate. The *dorsal* face (D) is slightly convex, but is free from irregularity, except that there is a deep notch (*h*) in the centre of its inner margin. The two *lateral* faces (B, *i*, *i*) are perfectly flat; and their only feature is a large aperture (*g*, *g*) which each presents towards its internal margin. The *internal* face (B), which is comparatively small and irregular, shows near its dorsal margin a pair of large apertures (*e*, *e*), the edges of which are raised so as to leave a distinct furrow (*h*) between them; this furrow, which has shown itself as a notch in the inner margin of the dorsal face (D, *h*) is continued onwards towards the ventral margin, but is more or less interrupted by the irregular processes which extend themselves to meet the rosette (§ 31), and which not unfrequently complete these furrows into canals (Plate XXXIII. fig. 1).—The *external* face is divided by a strong transverse ridge (A, *a*, *a*) into an upper and a lower portion; and the upper is again divided by a less elevated transverse ridge, and by median continuations of the ridges already noticed on the upper surface, into two pairs of fossæ, *b*, *b*, and *c*, *c*. Of these the upper pair

are the deeper; and they afford a surface of considerable extent for the attachment of the two great flexor muscles of the Ray, which fill up the whole space between the upper transverse ridge and the convex margins of the vertical plates, having an attachment also to the prolongations *d*, *d* of those plates, which stand forth as ridges bounding the median furrow. The shallower fossæ (*b*, *b*) give attachment to *interarticular* ligaments, of which the special function seems to be to hold together the plates; since I have always found, in pulling them asunder, that the greatest resistance is offered at this part of their articulation. The median furrow leads down to the large oval opening (*e*) of the radial canal, which partly interrupts the great transverse ridge. Below this ridge is a fossa (*f*) extending across the whole breadth of this surface, but especially deep in its median portion, for the lodgment of the *elastic* ligament which antagonizes by its extensile action the action of the flexor muscles.—The general disposition of the five pairs of flexor muscles passing between the First and the Second Radials, is shown in Plate XXXIV. fig. 2, m^1, m^1.

34. On removing the dorsal surface of the Pentagonal Base by the careful application of an acid (Plate XXXIII. fig. 1), or by making a section parallel to its dorsal surface, and in the plane of the openings which we have noticed in the internal, external, and lateral surfaces of each First Radial (Plate XXXIV. fig. 1, A, B), we find that these all belong to one system of Canals extending radially from the central space, and also forming an annulus around it. The two apertures on the internal face of each First Radial (§ 33) lead to two canals which converge towards each other, and which very quickly meet, so as to form a single canal (*a*, *a*) which passes directly towards the external margin; whilst each of the converging canals gives off a large lateral branch (*b*, *b*), which meets a corresponding branch in the adjacent radial; and thus the five great Radial Canals are intimately connected at their origin by an arrangement that reminds the Anatomist of the "Circle of Willis" at the base of the Brain.

35. *Rosette.*—The peculiarly-shaped circular plate which occupies the central vacuity in the Pentagonal Base (Plate XXXIII. figs. 2, 9), and which is shown detached in figs. 10, 11, may be described as consisting of a disk perforated in the centre, with ten rays proceeding from it, five of these rays (*a*, *a*) being triangular in form and nearly flat; whilst each of the other five (*b*, *b*) that alternate with these has parallel margins inflected on its ventral aspect in such a manner as to form a groove, whilst the ray curves to its dorsal aspect in such a manner as to bring this groove to the periphery of the rosette, and then terminates abruptly as if truncated. Around the central perforation we sometimes find on the ventral surface an irregular raised collar, obviously corresponding to the central passage of the annulus of the pentagonal base; but more commonly this is replaced by a number of vertical processes irregularly disposed (fig. 11). Its diameter, in a full-grown specimen, is about ·045 inch. When we look at this "rosette" *in situ* (Plate XXXIII. fig. 9), we find that the five triangular rays are directed to the sutures between the five Radials (*a*, *a*), their apices joining the contiguous pairs of these, just between their two adjacent apertures leading to the radial

canals; whilst each of the five spout-like rays joins the intermediate portion of one of the Radials, the inflected margins of the former being applied to the borders of the vertical furrow of the latter, in such a manner that the two grooves are united into a complete canal (*b*, *b*). Notwithstanding the apparent continuity between the calcareous reticulation of the Rosette and that of the Pentagonal Base at the extremity of each ray of the former, I am disposed to think the continuity not real, since, after boiling in a solution of potass, the rosette separates itself from the Radials without any positive fracture at these points. A real continuity, however, would seem to exist between the central prolongations of the first Radials (§ 33) and the discoidal portion of the rosette, these prolongations attaching themselves to it either separately, or after coalescing with each other either to a slight extent or so completely as to form the collar just described, and the junction being so complete that its separation can only be effected by fracture.

36. This "Rosette," when viewed only with reference to its own structure and its connexions with the surrounding base of the Calyx, is one of the most beautiful objects with which I am acquainted. But the interest attaching to it will be found greatly heightened, when the extraordinary process by which it is developed from the original Basals of the Pentacrinoid larva shall have been explained (§§ 89, 90); still more, when its relations to the soft parts lodged in the Centro-dorsal cavity and its Radial Canals shall have been displayed in the Second Part of this Memoir.

37. *Second Radials.*—Proceeding now to the other components of the Calyx, we find the Second Radial (Plate XXXVI. fig. 2) to be a somewhat discoidal plate of elliptic figure, having two nearly parallel faces, one *internal* or *central*, articulating with the First radial, the other *external* or *distal*, articulating with the Third radial. The internal face (A) is divided transversely (like the external face of the first radial) by a prominent ridge (*a*, *a*) that also passes round the large oval opening of the radial canal, and is then continued on either side of the median line to the upper margin of the plate, the two approximated ridges having a furrow between them. The large depressed spaces bounded by these ridges on either side, are again marked out by secondary ridges into two pairs of fossæ corresponding with those on the external face of the first radial (§ 33). Of these the upper pair (*c*, *c*) are the deeper, and are for the most part bounded by a pair of thin lamellæ extended upwards from the proper margin of the plate, as is obvious when we examine it from the distal side (B, *d*, *d*). These lamellæ give attachment to the distal ends of the flexor muscles; while in the shallower fossæ (A, *b*, *b*) are lodged the *interarticular* ligaments. Beneath the great transverse ridge is a broad fossa (*f*) that is particularly deep just beneath the opening of the radial canal (*e*); this gives attachment to the *elastic* ligament, the tension of which antagonizes the flexor action of the muscles. The external or distal face (B) is divided by a *vertical* ridge (*a*, *a*) that passes round the opening of the radial canal, into a pair of lateral fossæ (*b*, *b*), which give attachment to the interarticular ligaments that connect the second with the third radial, no muscular bands being here interposed.

38. *Third Radials.*—The Third Radial, when looked-at from above or from below

(Plate XXXVI. fig. 3, C, D), has a well-marked triangular form, presenting three articular faces; of these the central or internal looks towards the external face of the Second radial, whilst the face that looks obliquely outwards on either side serves as the base of an Arm. The internal face (fig. 3, A) corresponds very closely to that with which it is articulated, being divided, like it, by a *vertical* ridge, that also passes round the opening of the radial canal, into two lateral fossæ. When we look at this articular margin of the Third Radials from the dorsal side (D), we observe that its two lateral portions slope away in some degree from the median prominence; and this is also seen when we look at the articulation in section (Plate XXXIV. fig. 1) or on its ventral aspect (fig. 2). Hence, when the opposed ridges of the Second and Third Radials are in contact with each other, the third radial would seem to have some power of *lateral* movement upon the second. As no muscles, however, pass between the second and third Radials, which are connected by ligaments only, such movement, if it really exists, can only be attributed to the general contractility of the soft parts by which these plates are invested. From the upper margin of the internal face (A) we see projecting a pair of lamellæ (*d*, *d*) which do not form part of the surface of articulation with the second Radial, but which enter into the two oblique surfaces of articulation with the first Brachials. Each of these last faces (B) is formed upon the plan just now described as presenting itself in the opposed articular surfaces of the first and second Radials, having the transverse ridge (*a*, *a*), the fossæ for the interarticular ligaments (*b*, *b*), the fossa for the elastic ligament (*f*, *f*), and the muscular fossæ (*c*, *c*) with their thin vertical lamellæ, the lamella (*d'*) that rises from the distal angle being common to both the oblique faces. The dorsal surface of this plate (D) presents no marked peculiarity; but on the ventral (C) a considerable inequality is occasioned by the projection of the three vertical lamellæ. The radial canal, as we should expect, here divaricates, one branch passing on to either arm (Plate XXXIV. fig. 1, *c*).

39. No trace of *Interradial* plates shows itself in the variety of *Antedon rosaceus* with which I am most familiar,—that, namely, which occurs in the estuary of the Clyde, in Strangford Lough, and in Kirkwall Bay. But in specimens from Ilfracombe and from Plymouth Sound of what, from their likeness in all other respects, I cannot but regard as belonging to the same specific type, I find certain small plates in the angles between the Second and Third Radials, which are obviously those referred to by Mr. J. S. MILLER in his *Comatula fimbriata* from Milford Haven as "intercostal plates or joints"[1]. Although MILLER figures only *one* such plate in each angle (which may be readily understood from his having only employed a low magnifying power in examining it), yet I find that, generally speaking, it is resolvable by the Microscope into a cluster of three or four small plates (Plate XXXIII. fig. 7, B), though it is not unfrequently found to consist of an aggregation of *several* minute bodies (fig. 7, A) scarcely larger individually than the fragments of calcareous reticulation often occurring in the ventral perisome (Part II.). Moreover I learn from Professor WYVILLE THOMSON that in a specimen recently dredged off Shetland by Mr. BARLEE, these plates were present in three of the angles, but

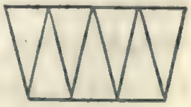
---

[1] Natural History of the Crinoidea, Frontispiece, fig. 2, G.

were wanting in the other two. Hence I cannot but agree with him[1] in regarding them as non-essential parts of the skeleton, belonging to its *perisomatic* and not to its *radial* system (§ 84).

40. *Arms.*—Each of the ten Arms formed by the bifurcation of the Rays, is composed of a long succession of segments, gradually diminishing in diameter from its base to its termination. The *number* of these segments appears to me to have no definite limit; for in every case in which the arm has presented the aspect of completeness, I have found its termination exhibiting the same indications of continued growth as are manifested by it when obviously immature (§ 67). It is remarkable that although the forms and proportions of the segments vary widely in different parts of the Arm,—their length being four or five times their diameter near its extremity (Plate XXXVIII. fig. 4), less than twice their diameter about its middle (Plate XXXVII. fig. 1), and less than half their diameter near its base (Plate XXXVII. fig. 3),—this diversity almost entirely results from the progressive increase in *diameter* which shows itself in the segments as we pass from the extremity towards the base; the *absolute* length of the segments being nearly the same throughout. The average length of each segment is rather less than ·03 inch; and thus in an arm of which the total length is 4 inches, we have about 140 segments. The general plan of their conformation is everywhere the same, each segment being fundamentally a cylindrical rod, perforated by an Axial Canal; and the departures from this form have reference chiefly to the attachment of the muscles and ligaments at the articular surfaces (Plate XXXVIII. figs. 2, 4). But the diversity in the proportions of the segments in the different parts of the Arms gives a great variety to their general aspect; and it will hence be desirable to describe separately the Basal, the Middle, and the Terminal portions of the Arms.

41. *Basal Portion.*—The diameter of the Arms near their base in a full-grown specimen is about ·07 inch; and this is maintained with little diminution for nearly a quarter of their length. When we look at them from the dorsal side (Plate XXXVII. fig. 3), we see that the *inner* margin (that is, the one which looks towards the other arm of the same Ray) of their *first* segments is so much shorter than their outer that, whilst the two articular facets of the Third Radial incline towards each other at an angle of about 80°, that angle is widened-out between the distal articular faces of the two first Brachials that rest upon it to about 130°; and that by a similar difference in the length of the inner and outer margins of the second Brachials, their distal articular faces are brought nearly into the same plane. Generally speaking, a like inequality shows itself between the inner and the outer margins of the succeeding segments, but in an alternating manner; so that their dorsal faces have the form of a succession of triangles, the apices of which point alternately to one side and the other, their vertical angles being about 40°. But there are many departures from the regularity of this arrangement; the most frequent being that which is produced by the close union of two segments having flattened articular surfaces whose plane is directly



---

[1] "On the Embryogeny of *Antedon rosaceus*," Philosophical Transactions, 1865, p. 540.

transverse to the axis of the arms, forming what is called a *syzygy* (*sg*),—a peculiarity which will be presently more fully described (§ 50). Excepting where syzygies occur, each segment after the first bears an articulated pinnule on its wider margin; and thus the pinnules spring alternately from each margin of the arm, the total of the two series equalling in number that of the segments, the pair forming each syzygy being counted as one. The articular facets for the basal segments of the pinnules, which are seen when the Arms are viewed on their lateral or their ventral aspects (Plate XXXVII. fig. 4, *p*, *p*), each consist of a shallow socket divided by a transverse ridge, which is perforated by a minute aperture. In this basal portion of the arms, the articular facet of the pinnule encroaches on the distal articular surface of each segment; but in the Middle and Terminal portions of the Arms, we shall find that in consequence of the change of relative dimensions of the segments, the pinnules are articulated to their lateral faces.

42. Even on the dorsal aspect of the Arms (Plate XXXVII. fig. 3), we notice that the margins of the successive segments do not come into close approximation except at the syzygies (*sg*, *sg*); and the spaces between them are occupied by an elastic ligamentous substance, which antagonizes the flexor muscles. These muscles (Plate XXXVIII. fig. 10) occupy the large spaces which are seen on the ventral aspect of the Arms, when the superficial soft parts have been cleared away (Plate XXXVII. fig. 4), to lie between the apposed faces of the segments; each segment being thinned away towards its upper or ventral margin into a vertical plate, from the middle of which projects on either side a sort of keel that forms a buttress and divides each of the deep fossæ left between the successive plates into two lateral halves. Where a syzygy occurs (*sg*, *sg*), the vertical plates of the two segments that form it come into close contact, and the keel projects only from one face of each, the two apposed segments thus taking the place of the single segment elsewhere. This peculiar contrast between the *dorsal* and the *ventral* aspects of the Arms is still better brought into view by a vertical section taken a little on one side of the axis of the arm, so as not to pass through the projecting keels that divide the muscular fossæ, and only partially to lay open the axial canal (Plate XXXVIII. fig. 11). This shows that the successive segments really come into contact with each other only by the great transverse ridges which cross their articular surfaces (Plate XXXVI. figs. 4–8, *a*, *a*), and embrace the opening of the axial canal; and that the space between these ridges and the *dorsal* surface, which is occupied by the elastic ligament, is much larger than it appears externally to be. Of the large space between the axial canal and the *ventral* margin, the part nearest the canal is occupied by the interarticular ligaments which are lodged in the shallow fossæ[1] that are seen on each articular surface just above the transverse ridge; whilst the much longer spaces intervening between the vertical plates are entirely filled by muscular substance (*m*, *m*), the fibres passing directly from each plate to the next in front and behind, except in the case of a syzygy.

---

[1] These are termed "articular facets" by Professor MÜLLER; but I feel satisfied that they cannot come into contact with those of the succeeding segment, and that they have the character above assigned to them.

Between the canal and the *dorsal* margin are shown the large elastic ligaments, *l*, *l*.—In Plate XLIII. fig. 6 is shown a similar section of a *decalcified* Arm, passing vertically along the median plane through the axial cord (*a*, *a*); so as to bring into view the muscles (*m*, *m*) lodged in the spaces intervening between the vertical lamellæ (s^1, s^1) of the successive segments, the interarticular ligaments (l^1, l^1) above the axial canal, and the great elastic ligaments (l^2, l^2) below it, lodged in the deep fossæ of the bodies of the segments (*s*, *s*).—In fig. 7 is shown a longitudinal section of a *decalcified* Arm passing horizontally through the axial cord (*a*, *a*); which exhibits the oblique disposition of the elastic ligaments (l^2, l^2), occasioned by the alternating obliquity of the segments; and also shows the interposition of the sarcodic radiations at the syzygies (*sg*, *sg*).

43. When the articular surfaces of the Brachial segments are brought into view by separating these segments from each other, we find them for the most part characterized by the same features as those which are presented by the opposed surfaces of the First and Second Radials (§§ 33, 37). With certain exceptions to be presently noticed, each is divided by a transverse ridge (which usually crosses it more or less obliquely) embracing the opening of the axial canal; and whilst the single deep fossa below this ridge gives lodgment to the *elastic* ligament by which the arm is extended, the pair of shallower fossæ above it serve for the attachment of the *interarticular* ligaments; whilst above these, again, are the pair of deep fossæ, formed by the recession of the vertically projecting lamellæ, in which the flexor muscles are lodged. From the peculiar shape of the brachial segments (§ 41), the articular surfaces generally incline to one side or the other, instead of looking directly forwards or backwards along the axis of the arm.

44. It obviously results from the general conformation of the segments, the peculiar disposition of their articular surfaces, and the arrangement of the muscles and ligaments, that provision is made for very free flexion of the Arm towards the ventral aspect by the contraction of its muscles; and this flexion can take place to such an extent that the arm may in a moment coil itself into a spiral resembling that of a watch-spring. When the muscular tension is relaxed, the elasticity of the ligament on the dorsal side of each segment straightens the arm, and may even flex it in some degree in the opposite direction; such dorsal flexion, however, never takes place to any considerable extent. The arms also possess a slight power of lateral flexion, in virtue, as it would seem, of an inequality of action in the two flexor muscles of each articulation; but this flexion is very limited in amount.

45. The Axial canal by which each segment is perforated, carries on through the whole length of the Arms the axial canal which divaricates in the Third Radial (§ 38); and it also gives off branches which in like manner enter the bases of the Pinnules, and proceed through their successive segments to their extremities. This canal is occupied by a *solid cord* of sarcodic substance, which I shall hereafter show to be really, like the similar cords that fill the canals of the dorsal cirrhi (§ 29), a branch of the original Crinoidal axis.

46. The peculiarities presented by individual segments of the Arms are most conspi-

cuous in the first five, every one of which may be readily distinguished from any other and it will be desirable, therefore, to describe each of these separately.

47. *First Brachial.*—It has been already shown (§ 41) that the inequality between the lengths of the inner and the outer margins of this segment (Plate XXXVI. fig. 4, C, D) is so considerable as to compensate in great degree for the extreme obliquity of the distal face of the Third Radial, to which it is articulated; and is such as even to occasion a curtailment of the inner half of each articular surface (fig. 4, A, C). The *proximal* articular surface (A) presents on its outer side no special peculiarity; but on its inner side we notice at the inner extremity of the fossa for the interarticular ligament a peculiar rounded pit (*g*), which might be supposed to be the socket for the articulation of a pinnule. This, however, is not the case; for no pinnule is borne by this segment, and the articular sockets of the pinnules are always found on the *longer* sides of the Brachial segments. The muscular fossæ are carried so far back by the recession of the vertical lamellæ which bound them, as to form the greater part of the ventral face of the segment (fig. C, *c*, *c*). The *distal* face (B) is formed on the plan of that of the Second Radial (§ 37); being simply divided by a vertical ridge (*a*, *a*) into two lateral fossæ (*b*, *b*), in which are lodged interarticular ligaments, but no muscles.

48. *Second Brachial.*—This segment presents a certain degree of resemblance to the preceding in general form, and, like it, has its outer margin so much longer than its inner as to produce a considerable obliquity between its articular surfaces (Plate XXXVI. fig. 5, C, D). But it is here the *proximal* face (A) articulating with the First Brachial, which is divided (like that of the Third Radial, § 38) by a vertical ridge into two lateral fossæ; whilst the *distal* (B), which articulates with the Third Brachial, bears a general resemblance to the proximal face of the First, but is at once distinguished by the excavation of its outer and upper portion (trenching on the outer muscular fossa) into the articular surface for the first pinnule (*p*, figs. B, E). But for this difference, the Second Brachial might be easily mistaken for the First Brachial of the other arm of the same ray.

49. *Third Brachial.*—The general form of this segment (Plate XXXVI. fig. 6) is more discoidal than that of either of the preceding; but it still has a decided obliquity (figs. C, D) between its proximal and its distal articular surfaces, which is, however, in the contrary direction to that of the First and Second Brachials (Plate XXXVII. fig. 3). The *proximal* face (A) presents the usual arrangement of fossæ for the lodgment of muscles and ligaments; the surfaces for the attachment of muscles being here chiefly provided by the two rounded lamellæ which project from the upper or ventral margin of the segment (*d*, *d*, figs. A, B). The *distal* face (B) shows a peculiarity of conformation which we have not yet encountered; for it is unmarked by any prominent ridges or fossæ, being in fact almost flat, except that it presents a series of slightly elevated ridges with alternating furrows, which radiate from the opening of the central canal towards the dorsal margin. The union of this face with the opposite face of the Fourth Brachial (*sg*, figs. C, D, E) constitutes what was designated by Professor J. MÜLLER a *syzygy*.

50. *Fourth Brachial.*—This segment (Plate XXXVI. fig. 7) has the same general form with the preceding, and the obliquity of its two faces (C, D) is in the same direction, the longer being again the internal. While the *distal* face of this segment (B) conforms to the ordinary type, and is distinguished from the proximal face of the Fourth segment (with which it might otherwise be confounded) by possessing an articular socket for the pinnule (*p*, figs. B, C, E), its proximal face (A) shows the same ridge and furrow arrangement as the distal face of the Third.—When we examine the Third and Fourth segments in their natural apposition (fig. 6, C, D, E), we see that the two sets of ridges are applied to each other (*sg*), leaving between them flattened passages that are formed by the correspondence of the furrows. The adhesion between these apposed surfaces is so close, that it can only be dissolved (like that of the First Radials to each other and to the Centro-dorsal plate, §§ 31, 32) by boiling in a solution of caustic alkali. No ligamentous substance is interposed between them; but an examination of decalcified specimens shows that the canals are occupied by radial extensions of the ordinary sarcodic basis-substance (Plate XLIII. fig. 2). The peculiar arrangement of these suggests that, like the "medullary rays" of an Exogenous Stem, they may serve to establish a communication between the "medullary axis" of this basis-substance which occupies the central canal, and the "cortical envelope" by which the surface of the segment is invested. When we come to study the development of the Brachial segments (§ 67), we shall find that the *syzygies* do not originate (as has been supposed by some) in an imperfect subdivision of segments,—no subdivision, perfect or imperfect, ever taking place; but that they are formed by a partial coalescence of segments originally quite distinct. For in the early stage of the existence of this animal as a detached *Antedon*, there is still so little specialization in the rod-like segments of the arms, that they are all nearly similar in form, have no proper articular surfaces, and are held together by nothing else than an imperfectly fibrous sarcodic substance. And whilst the majority of these gradually come to possess true articulations, and to be separated by the intervention of muscles and ligaments, a certain small proportion become more intimately united on a simpler plan, which admits of no motion between them. These *syzygies* are repeated at more or less frequent intervals along the greater part of the length of the arms; and as they are normally pretty constant in position in the several Arms of each individual, and in the several individuals of one species, whilst usually diverse in those of different species, it has been proposed by Professor J. MÜLLER to use them as characters of specific definition. To this it has been objected by DUJARDIN[1] that the syzygies are really variable in their number and in their mode of distribution on the several arms, especially when there has been a reparation after injury, so that on the same individual there may intervene from four to nine ordinary articulations between the corresponding syzygies. Whilst fully admitting the existence of irregularities thus originating, which are for the most part easily recognized, I am disposed to believe with MÜLLER that there is a normal type which is constant—as regards the basal portions of the arms at least—for each species,

---

[1] Histoire Naturelle des Zoophytes Echinodermes, p. 193.

and which may thus afford valid specific characters. In *Antedon rosaceus*, and what I believe to be its varietal forms (§§ 6, 7), the *second* syzygy (Plate XXXVII. fig. 3) occurs at the junction of the 9th and 10th segments, and the *third* at the junction of the 14th and 15th.

51. *Fifth Brachial.*—We now come to that which may be regarded as the ordinary form of the segments constituting the basal portion of the Arm, and which is repeated with great uniformity except where a syzygy intervenes,—the peculiar mode of articulation existing between the First and the Second segments not presenting itself elsewhere. Each articular face (Plate XXXVI. fig. 8, A, B) presents the same disposition of transverse ridges and ligamentous and muscular fossæ (*a*, *a*, *b*, *b*, *c*, *c*); and the same vertical lamellæ for the attachment of the muscles (*d*, *d*, figs. A, B, C) are common to both. The articular base of the pinnule is situated at the upper and outer margin of the distal articular surface (fig. B, *p*); and in this and the succeeding segments (in which its position is alternately on the inner and on the outer side) its presence always enables us at once to distinguish the distal from the proximal face of the segment. These faces are also distinguishable by the much greater inclination presented by the proximal face, the distal face being nearly vertical; this character, which repeats itself along the entire series of segments, is best seen on looking at the arm from above (Plate XXXVII. fig. 4) or in section (Plate XXXVIII. fig. 11).

52. *Middle Portion.*—As we pass from the basal portion of the Arms in the direction of their termination, we find in the first instance no other change in the conformation of the segments than is brought about by a considerable diminution of their diameter without a corresponding diminution in their length (Plate XXXVII. fig. 1). Thus in the segment of which the proximal and distal faces and the longer side bearing the pinnule are represented in Plate XXXVIII. fig. 5, A, B, C[1], we recognize the same arrangement of the great transverse ridge, the deep fossa for the elastic ligament between this ridge and the dorsal margin, the pair of shallower fossæ for the interarticular ligaments on the ventral side of the ridge, and the larger and deeper muscular fossæ chiefly formed by the vertical plates rising up on the ventral margin, with the articular socket for the pinnule encroaching on the muscular fossa of the longer side, that have been described in the last paragraph. But whilst the transverse and vertical diameters of this segment are scarcely more than half those of the Fifth Brachial, the length of the longer side is rather greater than less, so as quite to equal the transverse diameter. With this change of proportions there is an increased obliquity of the articular surfaces, alike in the transverse and in the vertical direction; and thus the spaces between the lamellæ for the attachment of the muscles that pass from segment to segment remain undiminished in length (Plate XXXVII. fig. 2), although those lamellæ are brought, by the reduction in the diameters of the segments, so much nearer to the axial canal of the arm. The articular sockets of the pinnules are now quite removed from the articular surfaces of the segments; and when two segments are united by syzygy (fig. 1, *sg*, *sg*), their conjoint

---

[1] These figures have been inverted by the Artist, so that the dorsal margin is uppermost.

length is but little greater than that of an ordinary single segment.—The same general proportions are maintained through a considerable part of the length of the Arm, the tendency being, however, to a further reduction in the diameter of the segments, without a corresponding reduction of their length; so that notwithstanding the increased obliquity of the articular surfaces, the muscular fossæ of the proximal and distal faces of each segment, instead of being separated merely by the thin vertical lamellæ which form the floors of both, lie as it were along its ventral surface, and yet do not come into close approximation.

53. *Terminal Portion.*—Passing onwards to the termination of the Arms, we find a progressive diminution in the diameter of the segments, without a corresponding reduction in their length; so that their proportions now differ widely from those of the basal segments (Plate XXXVIII. fig. 4). We still observe, however, an alternating obliquity in the disposition of their articular surfaces as seen from the dorsal side; a sort of notch being left, first on one side and then on the other, which is occupied by the elastic ligament. On separating the articular surfaces, we no longer find them presenting the characteristic ligamental and muscular fossæ; but there are nearly plane surfaces above and beneath the central aperture, to which the ligaments are attached, whilst the muscles lie in elongated fossæ excavated in the ventral face of the segments (*c*, *c*, fig. 2, A, B). The articular sockets for the pinnæ (*p*, *p*) show themselves on the lateral surfaces of the segments at about the middle of their length, and are quite removed from the muscular fossæ. —Of the normal mode of termination of the Arms, I am unable—after an examination of some hundreds of specimens—to speak with certainty; for I have never met with a specimen of this animal possessing in other respects the characters of maturity, which presented such a gradational diminution in the dimensions of the terminal segments as might be fairly expected from the general plan of its structure. In a large proportion of cases the Arms end so abruptly as evidently to show that their terminal segments have been broken off. And when they do present such a termination as is shown in Plate XXXVIII. fig. 4, this has all the characters of immaturity (§ 67); and must be regarded as marking, not the completion of the growth of the Arm, but either the continuance of its normal extension, or the reproduction of the portion which has been lost.

54. *Pinnæ.*—The pinnules with which the Arms are fringed (Plates XXXVII. figs. 1, 2, 3, XXXVIII. figs. 4, 10, 11) are composed of articulated segments nearly cylindrical in form, and gradually tapering from their base to their extremity, which bears a peculiar segment furnished with five or six minute hooks (Plate XXXVIII. fig. 3). The size and length of the pinnules vary considerably in different parts of the Arm, those near the base being not only longer, but also stouter in proportion to their length. The *first* pair of pinnules, which are attached to the Second Brachial segments, are much longer than those which succeed, often in fact attaining double their length; and these, as already mentioned, are nearly always seen in the living state bending over the ventral disk (Plate XXXI. fig. A). The first segment, which is articulated to the Brachial

segment that bears it by ligaments only, is much shorter than that which follows it (Plate XXXVII. fig. 3); and the length of the succeeding segments presents a considerable uniformity, until we approach the termination of the pinnule, where we often find a set of segments much shorter than the rest (Plate XXXVIII. fig. 3), suggesting the idea that these are the last formed. The number of segments in the pinnules is found by no means constant, when we compare either different pinnules of the same Arm, or corresponding pinnules in different individuals. Thus the *first*, which from their peculiar relation to the mouth I distinguish as the *oral* pinnules, very commonly have about thirty-five segments; but I have not unfrequently counted as many as forty, and in one instance forty-five. And while the ordinary pinnules of the *basal* part of the Arm have usually about twenty segments, the number not unfrequently rises to twenty-five. In the *middle* part of the Arm (Plate XXXVII. fig. 1) the number of segments in the pinnules may average eighteen; and in its terminal portion we find this rapidly diminishing from sixteen to half that number (Plate XXXVIII. fig. 4). The general conformation of the individual segments closely corresponds with that of the segments of the dorsal cirrhi (§ 28). They are nearly cylindrical, but somewhat compressed on their ventral aspect; and each of them (at least in the pinnules of the basal and middle parts of the Arms of well-developed specimens) has the dorsal margin of its distal end fringed by a set of short oblique spines (Plate XXXVII. fig. 3). The articular faces of the segments are formed on nearly the same plan with those of the segments of the dorsal cirrhi (§ 28), the opening of the central canal by which every segment is traversed, being surrounded by a slightly elevated ring, sometimes extended into a transverse ridge, and a depression being left by the bevelling-away of the surface in both directions, that serves for the lodgment of interarticular ligaments. But besides these depressions, there is in each of the basal segments, at least of well-developed pinnules, a small but deep notch in the ventral margin of each articular surface, but deeper in the distal; and this lodges a minute muscle (Plate XXXVIII. fig. 10), by the action of which the pinnules can be so flexed that those of the two sides of the Arm are brought towards each other, and also towards the line of its axis,—the converse movement of extension being effected (as in the Arms) by the elastic ligaments, when the muscles are relaxed.

REPARATIONS.

55. It is well known to Naturalists that a remarkable degree of reparative power is exhibited by ECHINODERMATA generally; and our *Antedon*, so far from constituting an exception, affords abundant exemplifications of its operation. For when we have the opportunity of examining a large number of specimens brought up together by the dredge, we are sure to meet with several which have obviously sustained losses either of entire Arms or of portions of Arms, and in which the lost parts are being reproduced on a smaller scale. We so often find that the fracture has taken place at a *syzygy* (Plate XXXVIII. fig. 6) that the question suggests itself whether there is any special reparative power at

this joint,—analogous to that which in the Decapod Crustacea is well known to exist in the basal extremity of the first phalanx. I am inclined to the belief, however, that the comparative frequency of fracture at the syzygies depends rather on the greater brittleness of the Arm at these points; the syzygal segments being held together only by sarcodic substance, instead of (as elsewhere) by ligaments and muscles. Certain it is that the reproductive power, instead of being limited (as in the Crab and Lobster) to one particular articulation, may be exerted at any point in the Arm, or even in the Ray. Thus we see in fig. 9 that a Ray has been torn off at the junction of the First and Second Radials; since not only the pair of Arms, but the Second and Third Radials which bear them are so much smaller than the rest, as to be obviously products of the reparative process. It is worthy of remark that the syzygies of these reproduced arms occur at the regular intervals. Another case of the same kind, in which the new Ray and Arms have attained a more advanced development, is shown in Plate XXXVIII. fig. 8, A. In other specimens in my possession, the reparation has commenced from the bifurcation of the Arms, from the articulation between the first and second Brachials, and from the articulation between the second and third; and here, again, it is interesting to remark that the first syzygy always occurs between the third and fourth segments, although there is often some irregularity (on the side of excess) in the interval between the first and the succeeding syzygies.—It is much more common, however, for only the terminal portion of an Arm to have been lost; and the new growth by which it is being replaced often affords a peculiarly good illustration of the mode in which the development of fresh segments is accomplished (§ 67).

56. It is curious that in some cases the act of reparation should be attended with Monstrosity; and this may be on the side either of *excess* or of *defect*. Of the former we have an example in Plate XXXVIII. fig. 8, B; where we see that a fracture having taken place at the articulation between the first and second Brachial segments, the new Second Brachial, instead of conforming to the ordinary type, resembles the Third or Axillary Radial, and gives support to *two* Arms, which have already attained a considerable development. A case of the latter is shown in the specimen represented in Plate XXXVIII. fig. 7, where the normal bifurcation of the Ray has not taken place, the Third or Axillary Radial being deficient, whilst the Second (which has about twice its normal length) bears a single Arm of full size, with its syzygies regularly repeated. Whether this monstrosity had its origin in fracture, however, may be doubted; and the like doubt may be entertained in regard to another case of "monstrosity by excess," which has presented itself to me in an oral Pinnule; a bifurcation like that of the Ray into a pair of Arms presenting itself at the second segment, so that two full-sized pinnules take the place of the ordinary single pinnule.

V.—DEVELOPMENT OF THE SKELETON.

1. *General History of the Pentacrinoid Larva.*

57. The study of the development of the pieces of which the Skeleton of *Antedon* is made up, will be best pursued in the first instance by following the general history of the development of its Pentacrinoid Larva, from the epoch at which Professor WYVILLE THOMSON'S account of it ceases, to the termination of its attached condition; since it will be in this mode that I can best make apparent the relation of the remarkable changes which the skeleton undergoes during this period, to the progressive evolution of the other parts of the fabric.

58. The nature of the objects to which the Pentacrinoid Larvæ attach themselves, varies with the locality. In Lamlash Bay, Arran, where my own studies of *Antedon* have been for the most part carried on, I have never found them affixed to anything else than the fronds of *Laminariæ* (to which the adult *Antedon* habitually clings), or to POLYZOA or *Spirorbes* attached to these. But at Ilfracombe, where *Laminariæ* are much less abundant, but where the Polyzoon *Salicornaria* grows in great luxuriance in the habitat of *Antedon*, the Pentacrinoid larvæ are found adherent to its stony Polyzoary. Mr. J. V. THOMPSON found them in the Bay of Cork "attached to the various species of *Sertularia* and *Flustracea* which occur in the deeper parts of the harbour of Cove, viz. in from eight to ten fathoms." Mr. WILLIAM THOMPSON (of Belfast) found them attached to *Delesseria sanguinea*. Hence I think it can scarcely be doubted that the Pentacrinoids will attach themselves indifferently to any Fuci, Polyparies, or Polyzoaries, which may abound in the habitats of the parent *Antedon*. Though generally scattered over the surfaces of these, so as not to be in any near proximity to each other, yet sometimes we meet with a group of several Pentacrinoids very close together, so as to present in one view all the stages in development represented in Plate XXXIX. I have one specimen in my possession, indeed, in which more than *seventy* Pentacrinoids, all nearly in the same stage of development, are attached to the surface of a patch of *Membranipora* that was encrusting a frond of *Laminaria*; and in another, which I owe to the kindness of Professor WYVILLE THOMSON, thirty-five Pentacrinoids, in that earlier stage which was first described by Professor ALLMAN, are so closely clustered together that the discoidal bases of their stems have come into mutual contact, and have acquired a polygonal form. These, he informs me, were bred in his Vivarium; and the circumstances of their aggregation were not a little curious. A pseudembryo, when losing its power of locomotion, was frequently seen floating in such a manner that its incipient discoidal base spread itself out (often in a stellate form) on the surface of the water, whilst the stem and body of the rudimental Pentacrinoid hung downwards from this; and it sometimes happened that by the approximation of a number of individuals in the same condition, the stellate extensions of the disks became mutually adherent. Similar clusters were found by Professor WYVILLE THOMSON attached to the inner surface of a dead valve of *Modiola modiolus*.

59. Referring to the admirable Memoir of Professor WYVILLE THOMSON[1] for full details of the early development of the Pentacrinoid Larva from the free pseudembryo, I shall briefly recall the principal features which it presents when it has fully assumed the Crinoidal type.—The animal consists in the first instance of *stem* and *calyx* alone, not even rudiments of arms being distinguishable. The stem is composed of from 8 to 10 cylindrical segments, the lowest of which is articulated to a discoidal plate which forms its base of attachment; whilst the highest expands to serve as the foundation whereon the plates of the calyx are built up. The calyx completely encloses the visceral mass, its oral valves, when drawn together, meeting over the mouth; whilst, when these open out, it has the form of an inverted bell[2]. Its lower or aboral portion is composed of five *basal* plates, which form by their approximation a five-sided pyramid with its truncated apex pointing downwards; whilst its oral part is composed of five *oral* plates, the approximation of which forms a similar pyramid with its truncated apex pointing upwards, though they are usually erected as separate valves, to allow the oral apparatus to be projected from within them. These two pyramids are the parts of the skeleton of the calyx which first make their appearance; and the one is so superposed on the other that the plates of the *oral* are *opposite* to those of the *basal* pyramid. At a somewhat later period the *first radials* make their appearance in the spaces left by the contiguous angles of the basal and oral plates, so as to *alternate* with these in position. Between two of the radials, and on the same level with them, an unsymmetrical plate early shows itself, the subsequent relation of which to the vent proves it to be an *anal* plate. From the summits of the first radials, the *second radials* are next seen to bud forth between the bases of the orals; and as the circle formed by these last does not increase in diameter, whilst the ring of first radials on which it rests has become larger, the orals are relatively carried inwards, whilst the second radials project somewhat outwards.—In the latest stage described by Professor WYVILLE THOMSON, the *third* or *axillary radials* have begun to show themselves at the distal extremities of the second; and rudiments of a pair of *first brachials* are distinguishable at the distal extremities of the third radials[3].

60. The several portions of the skeleton are imbedded in a nearly homogeneous sarcodic substance, which externally forms a perisomatic investment, and internally constitutes a lining to the calyx. The Digestive Cavity seems in the first instance to be simply excavated in the body-substance; but as the radial plates are developed, giving an expansion to the equatorial portion of the cup, the wall of the Stomach becomes separated from the lining of the calyx by a distinct perivisceral cavity filled with fluid, in which the stomach seems to hang attached to the body-wall here and there by sarcodic bands and threads. Simultaneously with the appearance of the anal plate, a slender digitate process rises from one side of the stomach and curves towards that plate; this constitutes the rudiment of the Intestine, but it has not as yet any outlet, and I believe it to be in this stage destitute even of an internal canal, being an extension of the *wall* of

---

[1] Philosophical Transactions, 1865, p. 513. [2] *Ibid.* Plate XXVI., figs. 1, 2. [3] *Ibid.* Plate XXVII. fig. 1.

the stomach but not of its *cavity*.—The mouth of the bell, when the oral valves are expanded, is entirely occupied by the oral apparatus. The mouth itself is a wide orifice, allowing the interior of the stomach to be plainly seen when looked into from above; and this is surrounded by a prominent ring from which arise the oral tentacles[1]. This ring is spoken of by Professor WYVILLE THOMSON as a proper "vessel;" but, as I shall show hereafter, although it doubtless represents the vascular ring which surrounds the mouth of Echinoderms generally, it is really an extension of the perivisceral cavity, partly separated from the rest. The oral tentacles are of two kinds, extensile and non-extensile. Of the former there are in the first instance only five, presenting themselves at the intervals between the oral valves; whilst of the latter there are ten, a pair lying within each of those valves. Coincidently with the development of the Radials, however, the first-formed extensile tentacles are carried outwards on diverticula from the oral ring, which thus originate the tentacular canals of the arms; whilst five additional pairs of extensile tentacles are developed between the five pairs of non-extensile, raising the whole number to twenty-five, of which the five first-formed are a little external to the rest. With the development of the second and third Radial plates that of the canal-system of the rays proceeds. The five "azygous" extensile tentacles are gradually carried outwards, by the prolongation of their respective diverticula, to the point of bifurcation of the Ray into Arms; and from these diverticula, which now constitute the *tentacular canals* of the rays, there arises on either side a series of delicate crescentic leaves, each of them having in connexion with it one extensile and two non-extensile tentacles[2]; an arrangement which afterwards comes to be repeated along the *arms* when they are developed at the bifurcation of the rays, and subsequently along the *pinnules* which fringe the arms of the adult. Beneath the tentacular canal a tubular extension of the perivisceral space passes along the ventral surface of each ray; and although this appears to form but a single canal, I shall hereafter show that it is very early divided by a horizontal partition extended from the membranous bands that suspend the digestive cavity in the perivisceral space; and that whilst the canal *above* the partition communicates with the portion of the perivisceral space which lies immediately round the mouth, the canal *beneath* the partition is extended from the portion of the perivisceral space which occupies the hollow of the calyx. The former I shall term the *subtentacular*, and the latter the *cœliac* canal; their relations will be found very remarkable.—The general aspect of the young Pentacrinoid, as seen with its tentacular apparatus retracted in a spirit-specimen, is shown in Plate XXXIX. fig. 1, A, for the sake of comparison with the later stages.

61. For some little time after the appearance of the arms, the relations of the skeleton of the calyx to the visceral mass it includes undergo but little change (Plate XXXIX. fig. 1, B); the chief difference consisting in the more compact condition it now comes to present, in consequence of the advanced development of its component pieces. The five *basals* (Plate XLI. fig. 1, *b*, *b*) now possess a regularly trapezoidal form; the

---

[1] Philosophical Transactions, 1865, Plate XXVI. fig. 3.

[2] *Ibid.* Plate XXVII. fig. 3.

lower part of each being an acute-angled triangle with its apex pointing downwards, and its upper part an obtuse-angled triangle with its apex directed upwards. The sides of the lower triangle are bordered by a somewhat thickened edge of solid transparent calcareous substance, the presence of which marks that the plate has received its full increase in that direction. The adjacent borders of these plates, however, do not come into absolute contact, a thin lamina of sarcode being interposed between them; and there is also a passage left at the truncated apex of the inverted pyramid formed by their junction, through which the axial sarcodic cord of the stem is continued into the calyx. The upper margins of the basal plates have no distinct border, and seem to be still in process of growth. The *first radials* (r^1, r^1) now form (with the *anal*, *a*, intercalated between two of them) a nearly complete circle, resting on the basals, and separating them entirely from the orals. Their shape is somewhat quadrangular; two of their angles pointing vertically upwards and downwards, and the other two laterally towards each other. Their lower angles are received between the upper angles of the basals; whilst on their upper, which are somewhat truncated, the narrow second radials (r^2, r^2) are superimposed. Considerable spaces still exist between the adjacent radial plates, except where the anal plate is intercalated in the series; and these are filled only by sarcodic substance. The central portion of these first radials is thickened by the endogenous extension of the calcareous reticulation; and this extends towards its upper angle, so as to form a kind of articular surface for the support of the second radials; but it does not extend over the lateral or alar expansions of these plates, which still retain their original condition of cribriform films. The *second radials* (r^2, r^2) differ completely from the first in shape, being rather rods than plates; but they are deeply grooved on their oral aspect, that which is subsequently to become a central canal being not yet closed in. The calcareous reticulation of their outer or aboral surface is cribriform; but the ingrowth from which they derive their solidity is produced, as Professor WYVILLE THOMSON has shown (p. 541), by the development of fasciculated tissue analogous to that of which the stem-joints are composed. The same general description applies also to the *third* or *axillary* radials (r^3, r^3), which, like the preceding, are nearly cylindrical at their proximal extremities, but expand towards their distal ends, so that each presents two articular surfaces, on which are imposed the pair of first brachials.—The *oral* plates (*o*, *o*), which alternate with the second radials, though somewhat internal to them, now present somewhat of a triangular form, their apices pointing upwards; their basal angles, however, are cut off (as it were) by the encroachment of the first radials. At no part of their contour have these plates any definite margin like that which borders the two lower sides of the basal plates; but the calcareous reticulation of which they are composed is continued into the layer of condensed sarcode with which they are invested. Although the form of these plates is generally triangular, yet their surface is not that of either a plane or a spherical triangle, but presents a remarkable unevenness. Near the apex of each there is a deep depression externally, and a corresponding projection internally; and the effect of this projection seems to be that, when the apices of these plates incline to one another, so as to form a five-sided pyramidal cover to the calyx (Plate XXXIX. fig. 2), the plates will close together not merely at their apices and lateral margins, but also at the upper part of their internal surfaces. There is also a broad depression near the base of each plate, so that its lower margin is somewhat everted. The *anal* plate (*a*), which is intercalated between two of the first radials, has a tolerably regular circular shape; but it consists of only a single cribriform film, and has no definite border.

62. Concurrently with the advance in the development of the Calyx, the Stem undergoes an increase both in the number and in the length of its component segments; and while it also increases to some extent in its diameter, its solidity is still more augmented by the endogenous growth of its calcareous skeleton. The cribriform plate on which it rests augments both in diameter and in thickness, absorbing into itself (as it were) nearly the whole of the organic substance of the basal disk. Its typical form may be considered as circular; but its margin is usually more or less deeply divided into lobes (Plate XXXIX. fig. 1). Its diameter is usually about ·015 inch. In its centre is a deep depression that lodges the end of the lowest joint of the stem.—It will be remembered that the development of each of the original segments of the Stem was shown by Professor WYVILLE THOMSON to commence by the solidification of a ring, which occupies what will afterwards become the middle of its length; and that from each of the two surfaces of this ring a hollow cylinder of calcareous trellis-work gradually extends itself. The *length* of each of these original joints is augmented by new calcareous deposit at its extremities, which finally become compactly rounded off and well defined, so that the apposed surfaces of two segments are clearly marked out from each other, instead of having their irregularities commingled, as in the earlier period of their formation. The *diameter* of each segment increases by new calcareous deposit on its cylindrical surface, bringing up its whole length to the size of the first-formed median ring, and finally giving to its extremities a slight excess beyond this. At the same time the *solidity* of each segment is increased by an inward extension of the calcareous trellis-work, which progressively fills up what was at first a hollow cylinder. This internal solidification, however, goes on more slowly than the completion of the external form and dimensions of the segments; for these may present their mature aspect, or nearly so, whilst possessing so little substance that their shape is altered, by the drying up of the soft sarcode-axis of their interior, to that represented in Plate XLI. fig. 4.

63. While the original segments, which are stated by Professor WYVILLE THOMSON to be *eight* in number, are thus advancing towards completion, new segments are being developed in the interval between the highest of these and the base of the calyx. None of my specimens in the stage now described present fewer than *twelve* segments; so that *four* at least must have been thus interpolated. That the upper end of the Stem is the part at which the new segments originate, is very plainly indicated by several considerations. It is there that, during the period in which the stem is continuing to increase, we always find the most rudimentary segments; and we may trace, as we

descend the stem, a gradual passage from such as consist of little else than the primordial ring, to those which have attained their complete cylindrical form and their full dimensions. Moreover it is obviously there that the nutritive activity will be the greatest; the sarcode-substance intervening between the base of the calyx and the summit of the stem being in most direct relation with that of the interior of the calyx (through the imperfect closure of its basal plates, § 61), and consequently with the visceral apparatus. And there is no other part of the stem in which there is the least appearance of any multiplication of segments, either by the subdivision of those already formed, or by the interpolation of new ones;—the suggestion of Professor ALLMAN, that the transverse ridges running round the centres of the segments may be the indication of such a division, being negatived by the facts already stated as to its real character. That this ridge, which is prominent in the segments of the upper and middle part of the stem, so far disappears in those of the lower as to be represented only by a single line, is due to the circumstance that the lower segments are those of which the skeleton is first completed.—By the time that the opening-out of the Calyx commences in the manner to be presently described, the number of segments in the stem has usually risen to 15 or 16; those of the inferior third of the stem are pretty nearly solidified throughout, only a small passage still existing through their interior; but those of the middle and upper thirds of the stem are still so far from having attained their completion, that their calcareous cylinders when broken across are found to be mere shells. The highest plate, on which the base of the calyx rests, is now distinguished from those below it by its somewhat larger diameter; but it does not as yet present any approach to the peculiar shape which it afterwards comes to possess.—The entire stem remains clothed with a thin layer of sarcodic substance; and its cavity is occupied by a cylinder of the same, which forms a continuous axis throughout its entire length, and passes up at its summit into the calyx. I have not been able to see any traces, at this early stage, of that fibrous structure which may be distinguished about the ends of the segments at a subsequent time.

64. A very important change now takes place in the relations of the several parts of the Calyx and its contents, which gives to the body of the more advanced Pentacrinoid a much closer resemblance to that of the adult *Antedon*. For instead of being completely included within a calcareous casing, which not only supports it below, but can close over it above, the visceral apparatus which occupies the cavity of the calyx is henceforth to be merely supported by its skeleton; its upper surface losing all protection except such as is afforded by the infolding of the arms, and being extended into a disk of which the mouth only occupies the centre. This change is essentially connected with the increased development of the intestinal tube, which now forms a nearly complete circle around the stomach, and comes to possess a second or anal orifice. When we examine the composition of the calyx (Plate XXXIX. fig. 1, c, and fig. 3), we find that the original *basals* have undergone little if any increase, but that the *first radials* (r^1, r^1) are now much larger, and spread out so as to extend the base of the cup, instead of merely forming

its sides. This spreading-out results from the increase in their own breadth, without a corresponding increase in the diameter of the circle on which they rest; so that they are forced to extend themselves obliquely instead of vertically. The single *anal* plate (fig. 3, *a*), originally interposed between two of the first radials (r^1, r^1), being attached not so much to the neighbouring plates as to the visceral mass, begins to be lifted out (as it were) from between them with the development of the anal funnel, as is seen in Plate XL. fig. 2; and the space left by it is partly filled up by the lateral extension of the two radials between which it was previously interposed, but which do not yet come into mutual contact. The *second* and *third radials* (r^2, r^2, and r^3, r^3) also increase in all their dimensions, but particularly in breadth; and they thus assist in supporting the visceral mass, which, at the conclusion of this stage, extends itself as far as the bifurcation of the arms. The most remarkable change in the condition of the calcareous skeleton in this stage, however, consists in the altered relative position of the five *oral* plates (Plate XL. fig. 1, *o*, *o*). This circlet, like that of the basal plates, does not partake of the enlargement so remarkably seen in the radials; its diameter being neither increased by the growth of its component plates, nor augmented by their separation from one another. It continues to embrace the circle of oral tentacles, the diameter of which comes to bear a smaller and yet smaller proportion to that of the ventral surface of the disk, as the size of the latter is augmented by the development of the intestinal tube around the gastric cavity; and thus it comes to pass that the circlet of oral plates detaches itself from the summits of the first radials on which it was previously superimposed, and is *relatively* carried inwards by the great enlargement of the circle formed by the latter,—the space between the two series being now filled in only by the membranous perisome, which is traversed by the five radial canals that pass out from the oral ring between the oral valves to the bifurcation of the arms, as shown in Plate XL. fig. 1.

65. In the earlier part of this stage, a continued increase takes place in the number of segments of the Stem, by the development of new rings at its summit; whilst the previously-formed segments of its middle and upper portions become progressively elongated and solidified, as those of the lower portion have previously been. At or about the period, however, at which the change already described is taking place in the relations of the oral and anal plates of the Calyx, the production of new calcareous segments in the stem appears to cease; and a remarkable change begins to show itself in the one on which the calyx rests. Instead of increasing in length, its original annular disk augments in diameter, becoming convex on its lower surface, and concave on its upper; and it extends itself over the bottom of the calyx, in such a manner as to receive into its concavity the apices of the basal plates. This change commences whilst the calcareous segments next below are still rudimentary; so that although no further increase in the number of segments takes place subsequently, yet some increase in its length will still be effected by the completion of the last-formed segments, previously immature. The total number of segments in the fully-developed Pentacrinoid stem is subject to a

good deal of variation. I have counted as many as 24, and as few as 16; the average may be considered about 20.

66. Soon after the highest segment of the Stem begins to enlarge, we notice on that portion of its under surface which extends itself beyond the segment whereon it rests, one or more minute tubercles, which are the origins of the dorsal cirrhi. Each of these tubercles is formed by a projection of the sarcodic substance of the perisome, within which are observable one or more minute annular disks of calcareous reticulation. The projection of the tubercle gradually increases, and the number of disks (which are the rudimental segments of the dorsal cirrhi) is multiplied; so that each incipient cirrhus presents the form of a short cylinder marked by transverse annulations (Plate XL. figs. 1, 2, *cir*). The length of this cylinder is progressively augmented by the formation of new disks, and by an increase in the thickness of the earlier ones; and the terminal segment soon presents an indication of the peculiar character it is ultimately to assume. Hence it is obvious that the new segments cannot be added at the extremity of the tentacle; and since, during the whole progress of its growth, we always find that the basal segment is the shortest, it seems most probable that the increase in the number of segments is effected by the interpolation of new segments at the point at which the cirrhus springs from the plate which bears it,—a conclusion which is conformable to what has been already stated (§ 29) of the relation of the cirrhi to the peculiar modification of the central axis contained within the centro-dorsal basin.—As each cirrhus elongates itself, its extremity, which was at first bluntly rounded, becomes pointed, the terminal segment developing itself into a conical form, though still covered with the same thick investment of condensed sarcode as extends over the entire length of the rudimentary cirrhus. —The exactness with which *radial symmetry* is maintained throughout the formation of the skeleton of this organism (save in the case of the Anal plate, which has special reference to the visceral mass), would lead us to anticipate that the first five cirrhi would be put forth together, radiating from the central tubercle, and developing themselves at corresponding rates. This, however, is not the case, for they are developed successionally, the first of them usually exhibiting numerous segments with a conical termination by the time that the fifth makes its appearance (Plate XXXIX. fig. 1, D). The cirrhi of the first whorl alternate in position with the rays, so that one of them is opposite to the anal plate; and this I generally (though not always) find to be the latest in its development, the most advanced being the one which corresponds in position to the commencement of the intestine.

67. The development of the Arms continues to take place on the plan already described in detail by Professor WYVILLE THOMSON. Each of them is terminated by a "growing point" of condensed sarcode, in which new segments successionally originate (Plate XXXVIII. fig. 1), a cribriform calcareous film being first formed on the dorsal face, and an ingrowth of fasciculated calcareous tissue then taking place in such a manner as in the first instance to leave a deep groove on the ventral face, which is afterwards converted into a canal by the closing-over of its margins; so that the transverse section which at first

resembles a horseshoe finally comes to be a ring. I feel quite satisfied that there is no interpolation of new segments (as some have supposed) either at the base or at any part of the length of the arms, their longitudinal growth being effected in part by the addition of new segments to their extremities, and in part by the augmentation in the length of each individual segment. Thus the average length of the basal segments of the arms in this stage of Pentacrinoid life is about ·007 inch, and their diameter about ·003 inch; whilst in the adult *Antedon* their length averages about ·03 inch, and their diameter about ·07. As the skeleton of the arms increases in length, their vascular apparatus is prolonged, and new groups of tentacles are developed from its extensions, each of these consisting, as before, of a leaf-like expansion with three tentacles proceeding from its base, of which one is much more extensile than the other two. The sarcodic substance which unites the pieces of the skeleton now begins to show a delicate fibrous texture at their adjacent extremities; but no separate fibres are as yet to be distinguished.

68. The changes which we observe during the later stages of Pentacrinoid life (Plate XXXIX. fig. 1, D, E) form in every respect a continuation of those already described. The Calyx is still more opened out by the increased lateral as well as longitudinal development of the first radials; but the diameter of the visceral disk augments in even larger proportion, so that it extends nearly as far as the bifurcation of the arms. The oral circlet is thus separated by a much wider interval from the periphery of the disk; and in this outer ring the anal funnel (Plate XL. fig. 2, *v*) is now a very conspicuous object, the *anal* plate (*a*) which it bears on its outer side being altogether lifted out from between the two first radials which it originally separated. Before the body of the Pentacrinoid drops off its stem, an incipient absorption of the *oral* plates is discernible; this absorption commencing along the margins of the apical portion, so that these plates lose their triangular form and become somewhat spear-shaped. The *second* and *third radials* exhibit an increase in all their dimensions, without much departure from their original form.

69. The Arms continue to increase in length, both by the addition of new segments, and by the growth of those previously formed; and it is when they have attained the length of about ·08 inch, and consist of about twelve segments, that we see the first indication of the development of *pinnæ*. This shows itself, not (as might have been expected) at the base or oldest part of the arm, but at its growing extremity, which now presents a bifurcation (Plate XL. fig. 1), the two rami being in the first instance almost equal, and each tumefied at its extremity by an accumulation of sarcode-substance. One of these rami, however, grows faster than the other, and soon takes a line continuous with that of the axis of the arm, from which the other diverges at an acute angle; so that the former comes to be the proper extension of the Arm, whilst the latter soon takes on the characters of a Pinnule. Ere long, however, the growing point of the arm again subdivides; two branches are formed, as previously; and whilst one of these becomes a continuation of the arm, the other is soon to be distinguished as a pinnule

given off from it on the side opposite to that of the first-formed pinnule. Thus the formation of the first pair of pinnules takes place in such a manner that the extremity of the arm presents an appearance in the first instance of *bi*furcation, and then of *tri*furcation. The new segments henceforth added to the extremities of the arms are all pinnated; the pinnules (whose skeleton consists, in this stage, of six or eight simple cylindrical segments) being developed alternately from one side and the other, and being furnished with extensions of the tentaculiferous apparatus of the arms. Owing to the thickness and opacity of the cumulus of condensed sarcode in which they originate, I am not able to speak with positiveness as to the mode of formation of their calcareous skeleton; but I believe it to take place rather after the manner of the joints of the stem and dorsal cirrhi than after that of the segments of the rays and arms,—that is, to commence with a complete ring which extends itself longitudinally into a hollow cylinder, rather than by a cribriform plate which wraps itself (so to speak) around the extension of the sarcodic axis (§ 67). It is remarkable that the basal portions of the arms, which had been developed previously to the first appearance of the terminal pinnules, remain destitute of these appendages to the end of the Pentacrinoid stage; except in the case of the *second* segment, from which, on each arm, an *oral* pinnule (§ 54) is developed.—The connexion of the segments of the arms by distinct fibrous tissue is now clearly discernible; but this tissue corresponds rather with the *ligamentous* than with the *muscular* tissue of the adult *Antedon*.

70. The Stem, in this later stage of Pentacrinoid life, shows no increase in the number of its segments; but those last formed near its summit are developed to almost the same length as the rest; and all the segments are somewhat augmented in diameter towards their extremities, so as to present somewhat of the dice-box form. The original annulus, which is still distinguishable in the middle of their length, so far from constituting a projection, now lies in a hollow. The axial cavity, if not quite obliterated by the filling up of the segments, is very much contracted; on this point it is difficult to arrive at a positive determination. The connexion of the segments by a distinct fibrous tissue, resembling that of the arms, and not merely passing from one articular extremity to the other but also embracing the contiguous extremities which it connects, now becomes obvious.—The most important change which the stem presents at this period consists in the enlargement of its highest basin-shaped segment, from which the dorsal cirrhi are developed, and in the further development and multiplication of the cirrhi themselves. This segment, which now presents the aspect in miniature of the centro-dorsal plate of the adult *Antedon*, augments not only in absolute but in relative diameter, extending itself over the dorsal or outer surface of the basal plates, which, at the time of the detachment of the body from the stem, are almost entirely concealed by it. The first-formed whorl of cirrhi now shows itself ready for prehensile action, its terminal claws being hooked, the calcareous segments being bevelled off on their dorsal aspect so as to allow of the downward flexure of the cirrhi, and a considerable amount of contractile fibrous structure being developed between and around the extremities of the segments. A second

whorl of cirrhi is now developed after the same manner as the first, between the latter (with which it alternates in position) and the base of the calyx (Plate XLII. fig. 3); and a third whorl generally makes its appearance before the detachment of the Pentacrinoid, so that the young *Antedon* possesses *ten* cirrhi in different stages of advanced development, and from *one* to *five* still rudimentary.

71. The total length of the full-grown Pentacrinoid, from the base of the Stem to the extremities of the Arms when these are folded together, may be about ·7 inch, that of the stem alone being about ·25 inch; when, on the other hand, the arms are fully expanded radially, the diameter of their circle may be about ·5 inch. At this period the body and arms usually possess a decided colour, which is sometimes sulphur-yellow, sometimes light crimson, sometimes an intermixture of both hues; this is usually more pronounced in the arms than in the body, and is entirely due to the development of pigmentary matter in the minute pyriform vesicles scattered through the sarcodic layer which still forms, as in the earliest phase of embryonic life[1], the general envelope of the body and its appendages.

72. The precise stage of development at which the body of the animal becomes detached from the stem, varies, like that at which a ripening fruit drops off its stalk, according to circumstances. I have met with specimens still attached to their stems, which were larger and more highly coloured than others which were found free; and I have repeatedly noticed that when kept in captivity they fall off quite spontaneously at an earlier period than that at which they detach themselves under ordinary circumstances. But the detachment does not seem to take place normally, until the dorsal cirrhi are sufficiently developed to enable them to take the place of the stem functionally by giving the animal the means of attaching itself to fixed objects.

73. *Habits.*—Concerning the habits of the Pentacrinoid I have little to add to what has been already noticed by Mr. J. V. THOMPSON[2]. "The animal," he says, "possesses the power of bending or inclining the stem freely in every direction; and what is more remarkable, of twisting it up into a short spiral, and that, with a considerable degree of vivacity,—a kind of movement that has not been noticed except in the *Vorticellæ.*" He speaks of the arms as "at one time spreading outwards like the petals of a flower, at another, rolled inwards like an expanding bud;" and continues,—"From their structure and movements it can hardly be doubted that they serve to seize upon and convey to the mouth whatever has been destined for its food, and which probably consists in every minute animal its powers enable it to overcome." Now, whilst I am quite at one with this excellent observer as to the facts which he records, I differ from him in regard to their interpretation; for I have seen nothing to make me believe that in the *Pentacrinoid*, any more than in the adult *Antedon*, are the arms ever employed for prehension; whilst the existence of large vibratile cilia on the walls of the digestive cavity, as seen by Professor WYVILLE THOMSON in the early *Pentacrinoid*, and by myself in the more

---

[1] See Professor WYVILLE THOMSON'S Memoir, Philosophical Transactions, 1865, pp. 522, 535.

[2] Memoir on the *Pentacrinus Europæus*, p. 7.

advanced, as well as in the adult *Antedon*, sufficiently accounts for the ingestion of alimentary particles, without attributing to the arms any prehensile action. Neither the oral nor the brachial tentacles are ciliated[1]; but I have frequently noticed a rapid movement of particles along the radial furrows and their brachial extensions, which intervene between the parallel rows of leaflets and tentacles developed on either side of the tentacular canals, such as indicates the action of cilia along the floor of those furrows. And as this movement always takes place *from* the extremities of the arms *towards* the mouth, I feel little doubt that it serves the purpose of bringing within reach of the ingestive current maintained by the gastric and intestinal cilia such alimentary corpuscles as settle down upon the expanded arms and pinnules.

2. *Development of the Component Pieces of the Skeleton, from the commencement of the free or unattached stage.*

74. Having thus traced the history of the Pentacrinoid Larva to the stage at which it assumes its adult condition as a free *Antedon*, I shall describe in some detail the several pieces of which its skeleton is then composed; and shall then trace the further development of each to its final completion.

75. Beginning from the base, we have first to speak of the *Centro-dorsal* plate, or rather basin; which, as was rightly stated by Professor J. Müller, is really the highest joint of the Pentacrinoid stem; whilst, as pointed out by Professor Wyville Thomson[2], "it represents a coalesced series of the nodal stem-joints in the stalked Crinoids." Of this sagacious determination I shall hereafter (Part II.) adduce a most curious and unexpected confirmation. The centro-dorsal plate (Plate XLI. fig 2, *c*) at the stage now treated of, has the form of a basin with its lip *in*verted instead of *e*verted; its diameter is about ·03 inch, and its height about ·012 inch. Its basal surface is somewhat depressed in the centre; and here we may for a time distinguish a minute five-rayed perforation (fig. 6, *c*), which previously formed the communication between the cavity of the basin and the central canal that is still left in the upper segments (at least) of the stem. This perforation, however, is very soon closed up by an extension of the calcareous network, so that no trace of it remains visible either externally or internally. Around the stellate aperture is seen a circular series of five sockets for the articulation of the dorsal cirrhi, each of them having a pore in its centre, which is usually at the summit of a minute elevation. This pore gives passage to a sarcodic thread which proceeds from the sarcodic axis contained within the cavity of the basin, and runs along the central canal of the cirrhus to its termination. A second series of sockets, alternating in position with the first, is seen nearer the upper margin of the basin. This margin,

---

[1] Mr. J. V. Thompson speaks of the brachial tentacula as "furnished with capitate cilia, alternately placed along their sides;" but it is clear that he referred to the tubular processes of the tentacles which have been described by Professor Wyville Thomson (p. 526), and that, writing in 1827, he did not employ the term *cilia* in the technical sense to which it is now limited, but merely meant distinct hair-like filaments.

[2] Philosophical Transactions, 1865, p. 536.

when viewed from above, is somewhat pentagonal; but the opening left by the inversion of the lip is nearly circular. Looking down into its cavity, we may distinguish what was once the central canal (now blocked up), and the pores leading to the articulations of the cirrhi.

76. The circlet, or rather pentagon, of *Basal* plates (Plate XLI. figs. 5, 6, *b*, *b*), which is for the most part concealed externally by the centro-dorsal basin, is found, when exposed by the removal of the latter, to differ very little either in size or aspect from the circlet first completed in the Pentacrinoid (§ 59). The form of each plate (Plate XLI. fig. 2, B) is an irregular trapezoid, with its lower angle truncated; and it still retains the solid pellucid margin which originally characterized it. But it has undergone a remarkable thickening by an endogenous extension of its calcareous network; and this has taken place in such a manner as to leave its substance channelled out by a canal which commences at its lower truncated angle, and almost immediately bifurcates, the two branches diverging in such a manner as to pass towards the two First Radials which severally abut on the sides of the upper triangle of each basal (Plate XLII. figs. 6, 7). This canal gives passage to a large sarcodic cord that proceeds from the wall of a remarkable quinquelocular organ contained within the centro-dorsal basin, which I shall hereafter describe under the name of the "centro-dorsal vesicle," and which I shall show to be an expansion of the original Crinoidal axis, hollowed out into a multiple ventricular cavity. Each of the five primary cords (which originally lay on the internal surface of the basals forming the floor of the calyx) subdivides into two branches within the basal whose canal it enters; and thus each of the First Radials receives two branches supplied to it through the two basals whereon it rests.

77. The form of the *First Radials* (Plate XLI. fig. 2, R^1, fig. 5, r^1, and XLII. figs. 5, 6, r^1, r^1) is now that of a trapezium having its upper and lower sides nearly straight and parallel, whilst its lateral margins incline towards each other from above downwards. Externally they still present their original cribriform structure; and this is particularly obvious near the upper angles, where the first-formed perforated plate has not been thickened by internal addition. But whilst the external surface is convex, being arched from side to side, the internal is nearly plane, the concavity of the cribriform plate being filled up by an ingrowth of its calcareous reticulation, which still retains for the most part its original type. This ingrowth, however, takes place in such a manner as to leave two deep channels, which commence from the lower angles of the plate, and converge so as to meet in its centre, so as to form one large canal, which becomes completely covered in and passes to the upper margin of the plate, where it opens between the articular surfaces. These converging channels, when the plates are *in situ*, are continuous with the diverging canals of the two Basals whereon each Radial abuts; in such a manner that the primitive canal that enters each basal communicates by its bifurcation with the converging canals of two different radials; while the single canal of each radial is fed (so to speak) by the primitive canal of two different basals. At each of the lower angles of the radial, moreover, the wide embouchure of the converging channel is in proximity with that of its

adjacent radial (Plate XLI. fig. 5); and a continuity is thus established between the several parts of this canal-system, not only radially but peripherally. At the somewhat later period represented in Plate XLII. figs. 6, 7, the channels are completely covered in, so as to be converted into canals; and each embouchure is divided by a small calcareous islet into two passages, one of them opening opposite the canal of the basal, and the other opposite the corresponding canal of the adjacent radial. In this manner are formed the canals already described in the first radials of the adult *Antedon* (§ 34). The upper margin of the first radial now shows on either side of its centre an elevated articular surface (Plate XLI. fig. 2, R^1, *a*, *a*), the calcareous reticulation of which is much closer than that of the rest of the plate; and each of these gives attachment along its dorsal border to a distinctly fibrous *ligament* connecting it with the corresponding articular surface of the Second Radials; whilst from the ridges which form its ventral border there are now seen to pass towards the opposite face of the second radials a set of larger and more defined parallel fibres, which, from their similarity to those occupying the like position in the adult, we know to be *muscular*.

78. The *Second Radials* (Plate XLI. fig. 2, R^2) now begin to show a modification of their original nearly cylindrical form; being somewhat widened out at their lower end, so as to form two articular surfaces (*a*, *a*), which are not, however, directly opposite to those of the first radials, but slope away from them; so that whilst in close proximity with them on the dorsal face, where they are connected by ligament, they are separated by a considerable interval on the ventral side where muscle intervenes,—an arrangement which gives to the muscular fibres the length required for their efficient contraction. The upper end (*b*) of the second radial, however, is simply rounded off, presenting no proper articular surface; and it is connected with the base of the Third Radial by ligament only. Although the dorsal surface of the second radial is everywhere convex, its ventral face still shows a deep groove along its median line; this, however, is separated by a distinct layer of calcareous network from the axial canal beneath it, which opens at its lower end between the articular surfaces, and at its upper in the centre of the rounded termination.

79. The *Third* or *Axillary Radials* (Plate XLI. fig. 2, R^3) also show but a slight departure from the original simple type; their lower portion being incompletely cylindrical, whilst the upper is somewhat expanded laterally to form a pair of articular surfaces, which look obliquely towards either side, and are separated by a projecting median ridge. The lower extremity is rounded off, so as to resemble the upper end of the Second Radial, and shows, like it, the orifice of the axial canal in its centre; whilst each of the articular surfaces at its upper end shows a similar perforation, which is the orifice of one of the two branches into which the axial canal bifurcates in the interior of the segment, for the supply of the two Arms borne by it. The dorsal face of this segment is everywhere irregularly convex; but the ventral face has a deep depression in its centre, the bottom of which almost reaches the axial canal.

80. The segments which form the skeleton of the *Arms* (Plate XLII. fig. 5) at this

period, depart even less than the preceding from the simple type of conformation which they present at their first development (§ 67), being still obviously composed of the original cribriform plate, which constitutes their convex dorsal surface, with an ingrowth of fasciculated tissue that closes over the axial canal, and gives to the ventral aspect a flattened surface with a median groove. This ingrowth is most abundant towards the extremities, where also the meshes of the reticulation are smaller, so that these parts have a more solid character than the rest. We now begin to see that alternate inclination to one side and the other, which is so marked a feature in the articular extremities of the segments of the adult; and we also notice that whilst these extremities are in close contact with one another on the dorsal aspect (B), except where a small depression exists in each for the attachment of the articular ligament, the articular surfaces of the ventral face (A) slope away from each other so as to leave a considerable space for the lodgment of the two muscular bundles, which are now conspicuously interposed between each pair of segments in the basal part of the arms, with certain exceptions. These exceptions correspond with those which present themselves in the adult (§§ 47–50); though the peculiarities of conformation which mark them are as yet but little pronounced. Thus the adjacent extremities of the *first* and *second* brachial segments present nearly the same aspect on their ventral as on their dorsal face, no bevelling-off being seen on the articular surfaces of either; and they are connected by ligament only, no muscular fibres being here distinguishable. Again, the adjacent articular surfaces of the *third* and *fourth* segments come into yet closer contact, not even a connecting ligament being interposed, and the line of their junction being transverse instead of oblique; this prefigures the peculiar *syzygal* union which shows itself between these and other pairs of segments in the adult (§ 50).—Towards the extremities of the Arms, we find the segments even more cylindrical (Plate XLI. fig. 4, A, B), except where lateral processes are given off for the articulation of the pinnules; and their terminal faces are simply apposed to each other transversely, without either the alternate obliquity or the bevelled articular surfaces of the basal segments. And at the growing points of the Arms precisely the same rudimental condition of the segments presents itself (Plate XXXVIII. fig. 1), as that which has been already described (§ 67) as showing itself at an earlier period in their basal segments. Thus we may trace in one and the same Arm several successive stages of development of the pieces of its skeleton; the most advanced segments (those nearest the base of the arms) showing adumbrations of their adult peculiarities, although not yet departing in any considerable degree from their simple primitive type.

81. Besides the regular skeleton of the Arms, we commonly find their perisome of condensed sarcode to contain irregular branching spicules (Plate XLII. fig. 5, A, B), forming a sort of incomplete reticulation for the support of the elevated folds which constitute the margins of the ventral furrows. These are obviously the rudiments of the dermal plates which have been shown by Professor J. MÜLLER[1] to form a complete armour to the ventral perisome and its prolongations along the ventral surface of the arms in *Pen-*

---

[1] Über den Bau des *Pentacrinus Caput-Medusæ*, p. 48.

tacrinus Caput-Medusæ. It is curious that this perisomatic skeleton of the Arms, like the Oral plates (§§ 82, 94), subsequently undergoes complete absorption, so that no trace of it is discoverable in the adult *Antedon.*

82. The only portions of the skeleton of the young *Antedon* now remaining to be described are the Oral and the Anal plates; and respecting these there is but little to be said. The only change which the five *Orals* have undergone consists in a further advance of the process of absorption, the commencement of which has been already noticed (§ 68). This process goes on with considerable rapidity during the period at which the pedunculate *Pentacrinoid* is being transmuted into the free *Antedon*; and as the epoch of its detachment from the stem is not always precisely the same (§ 72), so the amount that has been removed by absorption at that epoch varies in different specimens. In some we find the upper half or even two-thirds of each oral plate to have entirely disappeared; whilst in others the marginal portions only of the upper part of the plate have been removed, leaving a sort of central tongue projecting upwards from the basal portion. The single Anal plate (Plate XLI. fig. 2, A) still retains the elliptical form which characterized it from the time when it was lifted out from the circlet of radials (§ 64); and it seems to have undergone but little change in any of its dimensions, either by addition or absorption. It is still a simple cribriform film, of which the lower portion shows a closer texture and a more uniform margin than the upper; and it is not connected with any other portion of the skeleton, save by the general perisomatic substance.

83. The entire skeleton of the Calyx—putting aside the centro-dorsal piece as really belonging to the stem—may be described, according to the formula of MM. de Koninck and Le Hon (*op. cit.*), as consisting of the following pieces:—

Basals	5
Radials	5×3
Interradials	first, 1 (Anal). second, 5 (Orals).
Brachials.	10.

84. Professor Wyville Thomson, however, regards the skeleton as composed of two systems of plates, the *radial*, and the *perisomatic*; which he states to be "thoroughly distinct in their structure and mode of growth"[1]. The Radial system consists of the joints of the stem, the centro-dorsal plate, the radial plates, and the segments of the arms and pinnules. The Perisomatic system includes the basal and oral plates, the anal plate, the interradial plates sometimes seen between the second radials (§ 39), and any other plates or spicules that may be developed in the perisome of the disk or arms (§§ 39, 81). Whilst partly agreeing with him on this point, I find myself unable to accept his distinction to its full extent, since its basis is not in harmony with my own observations. "The joints or plates of the radial system," he says, "may be at once distinguished by their being chiefly made up of the peculiar fasciculated (or radial) tissue

---

[1] Philosophical Transactions, 1865, p. 540.

of parallel rods which I have already described, and by their being perforated for the lodgment of a sarcodic axis." The extended researches which I formerly made on the calcareous skeleton of ECHINODERMATA generally[1], would lead me to attach but little importance to the form of the reticulation as a differential character, since this often varies greatly in the several portions of a single plate; and Professor WYVILLE THOMSON is forced by his reliance upon it to regard the superficial cribriform portions of the radial plates and even of the arm-joints as belonging to the perisomatic system,—a supposition which seems to me inconsistent with the fact that the ingrowth of the calcareous reticulation in the First Radials, by which the axial canal is at first formed as a groove and is afterwards covered in (§ 77), takes place on the cribriform, not on the fasciculated type. In fact there is no distinction in texture between the endogenous additions by which the *first radials* and the *basals* are respectively thickened; so that we cannot place them in separate categories on this score. But further, we have seen that in the stage now described, the Basals as well as the Radials are perforated to give passage to the radiating extensions of the sarcodic axis of the stem, which only reach the radials *through* the basals; so that this ground of distinction also fails to separate them.—I am myself disposed, however, to regard the perforation or non-perforation by the radiating extensions of the Crinoidal axis as quite sufficient in itself to differentiate the entire skeleton into two series of plates, which, with Professor WYVILLE THOMSON, I should term the *radial* and the *perisomatic*; but I should rank the Basal plates with the former, instead of with the latter.

85. I shall now describe the changes which each of the component pieces of the skeleton undergoes in its progress towards the type which it presents in the fully-developed *Antedon*.

86. *Centro-dorsal piece.*.—Through the whole period of growth, the increase of this segment takes place at a greater rate than that of any other part of the skeleton; so that it soon comes to pass beyond the circlet of Basals, and to abut on the proximal edge of the First Radials; and instead of stopping here, it continues to increase in diameter, until it conceals the whole inferior surface of the first radials, and sometimes even encroaches somewhat on the Second (Plate XXXII. fig. 1). When we examine into the conditions of this increase, we find them to bear a remarkable resemblance to those which prevail in the growth of the skeleton of Vertebrated animals. For when we bear in mind the form of the basin, with its cavity and inverted rim (§ 22), and witness its augmentation in size from its original diameter of ·005 inch to its final diameter of ·16 inch, with a corresponding augmentation of its cavity, it becomes obvious that there must be not merely a progressive *deposit of new material on the external surface*, but also a continual *removal of old material from the internal surface*, analogous in every respect to that by which the cavity of a cylindrical bone is enlarged by absorption from within, at the same time as the diameter of its shaft is augmented by the deposit of new layers of bone on its exterior.

---

[1] Reports of the British Association for 1847, p. 117 *et seq.*

87. With this general augmentation in size, there is an increase both in the number of sockets for the articulation of the Dorsal Cirrhi, and in the size of the individual sockets; and there is also a marked change in their disposition. I have not been able to satisfy myself that after the development of the first two whorls, each consisting of five cirrhi, any similar regularity is observable in their subsequent multiplication; but since, as I shall more fully explain hereafter, the real origin of each cirrhus is in a peduncle of sarcodic substance put forth from the central axis in the cavity of the centro-dorsal basin, and since the arrangement of the whole aggregate of such peduncles is distinctly verticillate, the want of a definite plan in the grouping of the cirrhi on the external surface of that plate seems attributable to their very close apposition. The new cirrhi always make their appearance between those previously formed and the base of the calyx, so that their sockets are close to the margin of the basin; and this is the position in which, as already stated (§ 26), we find those rudimental cirrhi that often present themselves even in the adult *Antedon*. The increase of the cirrhi in diameter is by no means proportional to the increase in the diameter of the centro-dorsal plate; so that not only is space made on its surface for the augmentation in the number of their sockets from 10 to between 30 and 40, but a vacancy gradually comes to be left in the central part of the exterior of the basin, which extends with its growth, and finally comes to bear a considerable proportion to its diameter (§ 22). This vacancy cannot be accounted for solely by the widening-out of the innermost circle of sockets by the general growth of the basin in the manner already described; and I feel no doubt that it is principally due to a progressive exuviation of the first-formed cirrhi from within outwards, concurrently with the development of new ones near the margin; those cirrhi which surrounded the summit of the stem being first shed, and their sockets being filled up by new deposit; and the space thus formed being gradually widened by the progressive exuviation of the cirrhi that bound it, and the filling-up of their sockets. For in comparing a series of centro-dorsal plates in different stages of development, I find distinct traces of such an obliteration of the original sockets; and when we come to study the connexions of the sarcodic axes of the cirrhi with that central Crinoidal axis, of which the portion not left behind in the Stem is included within the Centro-dorsal plate, we shall find additional evidence to the same effect.—Thus it appears that the total number of dorsal cirrhi developed during the life of any individual *Antedon*, considerably exceeds that which we meet with at any one epoch. How many of the earlier cirrhi are exuviated before the latest are put forth, I cannot state with certainty; but I should think that the number cannot average less than from 15 to 20, thus raising the total to at least 50.

88. Before leaving the Centro-dorsal basin, there is a further point of much interest to be noticed in regard to its growth; namely, the perforation of its wall for the passage of the new twigs which are given off from the central axis from time to time, and which, when they emerge on its external surface, become the sarcodic axes of the cirrhi. It scarcely seems probable that such perforations should be left as vacuities in the

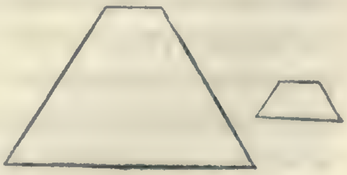
exogenous additions made to the calcareous reticulation, whilst the radiating sarcodic twigs for whose passage they are destined are prevented from gaining access to them by the imperforateness of the inner wall. And looking to the numerous examples which we have in the development of *Antedon*, not only of the *entire absorption* of some parts of the skeleton, but of the complete *remodelling* of others,—as shown in the growth of this very plate, and still more remarkably in the formation of the "rosette" from the original "basals" (§§ 89, 90),—I cannot but regard it as more probable that these cirrhal twigs, as they are successively put forth in the cavity of the basin and impinge upon its inner wall, have the power of forcing (as to speak) a passage for themselves, by inducing an absorbent action in that part of its substance that lies in their course towards the external surface.

89. *Basal Plates.*—The mode in which the "rosette" (§ 35) is formed by the remodelling and subsequent coalescence of the five Basals, and in which the sarcodic extensions of the central axis which are transmitted through the Radial plates to the Arms and pinnules, come to lie on the dorsal or external face of the "rosette," whilst they originally lay along the ventral or internal face of the basals, is certainly the most curious feature in the developmental history of the skeleton of *Antedon*.—It has been already shown (§ 76) that the cribriform plate of which each basal at first entirely consisted, is so much thickened by endogenous growth during the later stages of Pentacrinoid life, that the radial sarcodic cords come to be entirely invested by calcareous reticulation; and the floor of the ventral cavity shows no inequality as we pass from the central portion formed by the basals to the peripheral formed by the radials (Plate XLI. fig. 5). Very soon after the detachment of the young *Antedon*, however, a remarkable change begins to show itself in the basal pentagon, which is now entirely concealed externally by the extension of the centro-dorsal basin over its dorsal surface; for the cribriform film of which each basal plate was originally composed, and which still forms its external layer, now undergoes absorption, especially where it covers in the radial prolongation of the axis, so that the central space left by the incomplete meeting of the valves of the basal pentagon, is extended on its *external* aspect into five broad rays (Plate XLII. fig. 7, *b*), though on its *internal* or ventral aspect, where it is bounded by the last-formed portion of the endogenous reticulation, it shows no corresponding increase (Plate XLII. figs. 2, 6, *b*).

90. This removal of the older and outer part of each basal plate by absorption, and the consolidation of the newer and inner by additional calcareous deposit, go on at a rapid rate; so that in specimens whose size and general development show but little advance upon the earliest *Antedon* type, we find the basals already modelled into such a form that their coalescence will produce a somewhat unshapely "rosette." In Plate XLI. fig. 3, *a*, is shown the dorsal aspect of one of the basal plates in which the removal of the external layer has been carried so much further, that what is now left of it constitutes only a kind of thickened margin along those sides of the plate which are received between the First Radials; and by an extension of the same process along the median

line of each plate, until the external layer has been completely removed from its salient angle (fig. 3, *b*), the two lateral portions of that layer are separated from each other; and remain only as a pair of curved processes extending themselves from the inner layer in such a manner as to give to the plate when viewed from its ventral side somewhat the aspect of a saddle (fig. 3, *c*, *d*). When the five Basals thus altered are in their normal apposition, the curved process on either side each plate comes into contact with the corresponding process of its next neighbour; and the junction of the two forms a sort of ray curving towards the dorsal aspect. As each plate thus contributes the half of two of these curved rays, five such rays are formed between the five salient processes which are put forth by the internal or ventral layer, on the median lines of the five plates, and are received into the retreating angles formed by the junction of the First Radials. Very soon an actual continuity is established in the calcareous reticulation along the lines of junction, and the "rosette" is completed, as shown in Plate XLII. fig. 1, although the peculiarity of its shape becomes much more strongly pronounced with the subsequent increase of its size (Plate XXXIII. figs. 9–11).—Thus we see that the "Rosette" is essentially formed at the expense of the secondary or ventral layer of the original Basals, the ends of the curved rays being the sole residue of their primary or dorsal layer; and since, by the removal of the median portion of that layer in each plate, the radial cords are left bare on their dorsal aspect, they now pass from the central axis into the canals of the First Radials on the *outside* of the calcareous skeleton which occupies the central part of the base of the Calyx, instead of reaching these by passing (as they did in the first instance) along its *internal* face, or (as at a later period) through the *middle* of its substance.

91. *First Radials.*—In the passage of these plates from their rudimental to their mature condition, the principal alteration that we notice, besides an immense increase in size, consists in a change in the proportions of their principal dimensions, their thickness and solidity increasing much more rapidly than their superficial extension. This increase takes place in such a manner that the lateral portions of the plate are brought to the same thickness with the median, the dorsal and ventral surfaces becoming nearly parallel; and the lateral faces come to be flattened against each other, and to adhere so closely that by the apposition of the five plates a solid annulus is formed. The diameter of the central space of this annulus, which is occupied by the "rosette," does not increase during growth in nearly the same degree as that of its periphery, the size of each plate (it would seem) being more augmented by addition to its external face than to its lateral faces; so that the ratio of its breadth at its inner and its outer margins, instead of being (as at the conclusion of Pentacrinoid life) about 2 : 3, comes to be only 1 : 3, the shape of its dorsal face being thus changed from a trapezoid to a triangle with its apex truncated. Concurrently with these changes, we find that the various ridges and fossæ on the external and ventral faces of the plate (§ 33, Plate XXXVI. fig. 1, A, C), for the attachment of the muscles and



ligaments by which it is articulated to the Second Radial, are gradually developed into the form they present in the adult; and that the characteristic ridges and furrows of its internal face (B), with the prolongations that connect it with the ventral face of the rosette, make their appearance. All these features are marked out when the size of the plate is still minute as compared with that which it ultimately attains; and a little consideration will show that they cannot be maintained through each subsequent stage of growth, without a process of *modelling* analogous to that already described in the growth of the centro-dorsal and basal plates,—the first-formed portions of the calcareous skeleton being removed by absorption, whilst new deposits are being laid down elsewhere. If any further evidence of this be needed, it will be found in the enlargement of the Canals which are occupied by the radial prolongations of the central sarcodic axis, the diameter of these canals in the adult being at least equal to the whole breadth of the plate in the young.

92. *Second Radials.*—The alteration which the form of the Second Radials undergoes in their progress to maturity, is even greater than that of the First; for whilst they increase but little in the direction of their original length—*i. e.* in the space between their proximal and their distal faces,—they undergo a great augmentation both in breadth and in depth (Plate XXXVI. fig. 2), their proximal face attaining an equality in both dimensions with the distal face of the *first* radial to which it is articulated, and its distal face coming to present a similarly expanded surface to the proximal face of the *third* radial, in the place of the mere convexity in which the then cylindroid segment terminated at an early period (§ 78). This change in the proportion of the several dimensions of these plates begins to show itself very soon after the termination of Pentacrinoid life, as is seen on comparing r^2, r^2 in Plate XLI. fig. 6, and Plate XLII. fig. 7; and, as in the preceding instance, there takes place concurrently with their increase of size a gradual development of the prominences that give attachment to muscles and ligaments, with a deepening of the cavities that lie between them, as well as a progressive enlargement of the central canal.

93. *Third Radials.*—The change of form which the Third Radials undergo concurrently with their great increase in size, is scarcely less considerable than that of the Second; and the same tendency is manifested to lateral and vertical augmentation rather than to increase in radial length. The proximal face of the plate, which is apposed to the distal face of the second radial, rapidly increases both in width and depth; and comes like it to present an expanded surface, the ventral and dorsal margins of which form the bases of triangles formed by the ventral and dorsal faces respectively (Plate XXXVI. fig. 3, C, D). The entire sides of these triangles now form the margins of those lateral surfaces for the articulation of the first Brachials, which in the earlier period were merely a pair of facets somewhat inclined to each other on the distal extremity of the segment (Plate XLII. fig. 3, r^3). And these lateral articular faces, as they increase in proportional dimensions, come also to present prominences and fossæ similar to those that are characteristic of the distal faces of the First Radials, which they nearly equal in size as well as resemble in appearance. The central canal, with the branches into which it

bifurcates, is progressively enlarged by the internal absorption of its wall, as in the preceding cases.

94. *Oral Plates.*—The removal of these first-formed plates by absorption, which we have seen to commence before the termination of Pentacrinoid life, is completed very soon after the young *Antedon* has entered upon its free stage of existence. The absorptive process continues to take place from above downwards; and the last traces of these plates that can be distinguished, are seen as glistening fragments of calcareous network at the bases of five membranous valves which still fold over the tentacles forming the oral ring, in specimens which have attained a diameter of about an inch and a half. These soon disappear entirely.

95. *Anal Plate.*—This plate is still distinguishable in specimens that show no vestiges of the Orals; but it has undergone no increase in superficial dimensions, and is so far from being augmented in thickness that it seems rather to have been thinned by incipient absorption over its whole surface, preparatory to its complete disappearance a short time after. I do not find that either the upper part of this plate disappears before the lower (as we have seen to be the case with the Orals), or the lower before the upper; and as I have found no vestiges of it, though I have carefully sought for them, in young *Antedons* of about 2 inches in diameter, I conclude that the entire plate is removed at once by a continuance of absorption over its whole surface.

96. *Arms.*—It does not seem requisite to follow in any detail the development of the segments of the Arms; since the changes in conformation through which the first formed Brachial segments pass in their progress to maturity, are precisely analogous to those which have been already described in the Radials; and the successive production of new segments at the extremities of the arms takes place after exactly the same fashion as in the Pentacrinoid stage. The general tendency is to an increase in the *diameter* of the segments, which is relatively much greater than the increase in their radial *length* (§ 40); and with this there is an extension of their apposed articular faces, which gradually come to present the ridges and fossæ characteristic of the adult type, whilst at the syzygies these faces are brought into closer mutual approximation. The central canal by which each segment is traversed, undergoes a corresponding enlargement. The development of the Pinnæ from the basal portions of the arms, which for the most part remain destitute of them for some time after the first appearance of these lateral appendages (§ 69), takes place by the time that the Orals disappear; but these intermediate pinnæ are long in attaining the dimensions of those nearer the terminations of the arms. The increase of the Pinnæ in length, like that of the Arms themselves, partly depends upon an increase in the number of their segments, and partly on an augmentation in the length of each individual segment. How and where the new segments are added, I cannot certainly say; but it may be safely assumed that they are not developed at the terminations of the pinnules, since their peculiar terminal hook is formed when as yet the segments are few in number. And as the basal segment has a peculiar conformation for its articulation with the brachial from which the pinnule proceeds

(§ 54), I cannot think it likely that it is displaced from time to time by the interposition of a new segment between itself and the brachial. The most probable place for such interposition seems to be either between the basal and the second segment, or between the penultimate segment and the terminal claw-bearing segment. Since no such traces of incompleteness present themselves in the segments which follow the basal as would justify the former supposition, we seem compelled to adopt the latter; and it is not a little curious that the increase in the number of segments in the Stem, the Dorsal Cirrhi, the Arms, and the Pinnules should thus take place in different modes,—the new segments making their appearance in the Stem immediately beneath its highest segment (§ 63), in each Dorsal Cirrhus at its base (§ 66), in each Arm at its termination (§ 67), and in each Pinnule at the base of its terminal segment.

Explanation of the Plates.

PLATE XXXI.

Side view of *Antedon rosaceus* attached by its dorsal cirrhi to a stone; drawn from a living specimen in a Vivarium.—Magnified 3½ diameters.

A, Disk and basal portion of the Arms of the same, as seen from above; showing the manner in which the basal pinnules arch over the ventral surface of the disk.—Magnified 3½ diameters.

PLATE XXXII.

Fig. 1. Dorsal aspect of the Calyx of *Antedon rosaceus*, as seen after the removal of the dorsal cirrhi:—*c*, Centro-dorsal plate, entirely concealing the First Radials; r^2, r^2, Second Radials; r^3, r^3, Third or Axillary Radials; br^1, br^1, First Brachials.—Magnified 8 diameters.

Fig. 2. Ventral aspect of the Calyx, as seen after the removal of the visceral mass. Around the central depression is seen a circlet of *five* pairs of Muscles, passing between the First and Second Radials; and outside these is a circlet of *ten* pairs, passing between the Third Radials and the First Brachials (see Plate XXXIV. fig. 2).—Magnified 8 diameters.

Fig. 3. Ventral surface of the Visceral Disk, showing the mouth, *m*, in the centre, with five channels radiating from it, which form by their bifurcation the ten channels that pass along the Arms and give off branches to the Pinnules, the first and second of which on each arm assist in supporting the visceral mass; at *a* is shown the Anus seated on a proboscis-like funnel that rises between two of the Radial channels.—Magnified 8 diameters.

Fig. 4. Dorsal Cirrhi as seen radiating from the Centro-dorsal plate, *c*, to which they are articulated.—Magnified 15 diameters.

Fig. 5. Dorsal Cirrhi in various stages of growth and development:—*a*, typical mature cirrhus; *b*, *c*, *d*, *e*, *f*, successive stages of incomplete type; *g*, *h*, *i*, *k*, *l*, successive stages of complete type; *m*, *n*, cirrhi presenting most of the characters of maturity, but having less than the normal number of segments, and deficient in the opposing process.—Magnified 45 diameters.

PLATE XXXIII.

Fig. 1. Pentagonal Base of the Calyx of *Antedon rosaceus*, formed by the coalescence of the five First Radials, its dorsal surface (shown in fig. 2) having been removed, so as to lay open the radiating Axial Canals, *a*, *a*, and their communicating branches, *b*, *b*; around the central space is an irregular calcareous network, formed by the inosculation of processes sent off from the internal faces of the First Radials.—Magnified 25 diameters.

Fig. 2. Pentagonal Base of the Calyx, formed by the coalescence of the five First Radials, with the Rosette *in situ*, as seen from its dorsal aspect, the Centro-dorsal plate having been removed.—Magnified 25 diameters.

Fig. 3. Pentagonal Base of the Calyx, formed by the coalescence of the First Radials, as seen from its ventral aspect:—the central aperture for the passage of a prolongation of the Crinoidal Axis is surrounded by irregular processes from the inner margins of the First Radials, which connect themselves with the central portion of the Rosette; the oblique sides of the pentagon form the surfaces of articulation for the Second Radials.—Magnified 25 diameters.

Fig. 4. Centro-dorsal plate, seen from its dorsal side after the removal of the cirrhi; showing its flattened central portion surrounded by between two and three circlets of articular sockets.—Magnified 15 diameters.

Fig. 5. Lateral view of the same, showing the alternating arrangement of the sockets.—Magnified 15 diameters.

Fig. 6. Centro-dorsal plate, seen from its ventral side after its detachment from the Pentagonal Base, showing its basin-like cavity, the bottom of which is perforated by minute apertures for the passage of the axial cords of the cirrhi; on the inturned lip of the basin are five shallow depressions, *a*, *a*, corresponding to the spout-like processes of the Rosette.—Magnified 15 diameters.

Fig. 7. Portions of Base of Calyx at origin of Rays, in the variety showing Interradial Plates:—*c*, Centro-dorsal; r^2, r^2, Second Radials; r^3, r^3, Third Radials: at A these interradials are numerous, minute, and dissociated, and are obviously perisomatic in their character; at B they are fewer, larger, and more compactly arranged.—Magnified 30 diameters.

Fig. 8. Segments of Dorsal Cirrhi; *a*, basal, *b*, from middle of length; showing the central passage surrounded by a prominent annulus, with depressions on either side for the attachment of ligaments.—Magnified 70 diameters.

Fig. 9. Central portion of fig. 2 more enlarged, showing the Rosette *in situ*:—*a*, *a*, lines of junction of the First Radials; *b*, *b*, apertures formed by the coalescence of the spout-like processes of the Rosette with the inner margins of the First Radials.—Magnified 70 diameters.

Fig. 10. Rosette separated and seen on its dorsal aspect, showing its five flattened triangular processes, *a*, *a*, and its five intermediate spout-like processes, *b*, *b*.—Magnified 100 diameters.

Fig. 11. Rosette seen from the ventral side, showing around its central orifice irregular projections which coalesce with the processes given-off from the inner margins of the First Radials; *a*, *a*, triangular processes; *b*, *b*, spout-like processes.—Magnified 100 diameters.

PLATE XXXIV.

The following References are common to both Figures:—

r^1, r^1, First Radials.
r^2, r^2, Second Radials.
r^3, r^3, Third or Axillary Radials.
br^1, br^1, First Brachials.
br^2, br^2, Second Brachials.
br^3, br^3, Third Brachials.
p, *p*, Pinnules.

Fig. 1. Horizontal section of Calyx and basal portions of Arms of *Antedon rosaceus*, flattened out; showing the axial canals, *a*, *a*, of the Rays which communicate by circular branches at *b*, *b* (as in Plate XXXIII. fig. 1), and bifurcate at *c*, *c*, to pass into the Arms.—Magnified 18 diameters.

Fig. 2. Interior of the Calyx with basal portions of Arms, of a young *Antedon*, to show the disposition of the Muscles:—m^1, m^1, five pairs of muscles passing between the First and Second Radials; m^2, m^2, ten pairs of muscles passing between the Third or Axillary Radials and the First Brachials; m^3, m^3, ten pairs of muscles passing between the Second and the Third Brachials.—Magnified 30 diameters.

PLATE XXXV.

Fig. 1. Vertical Section of the Centro-dorsal Piece; consisting of the Centro-dorsal plate which forms the dome of the cavity, and which is anchylosed at the lines *a*, *a*, *a*, *a* to the First Radials; *b*, *b*, canals leading to the articular sockets of the cirrhi; *c*, basal segment of a cirrhus; *d*, *d*, axial canals of First Radials; *e*, *e*, portions of Second Radials; *f*, Rosette.—Magnified 70 diameters.

Fig. 2. Longitudinal Section of three of the basal segments of a Dorsal Cirrhus, showing the central articular processes, and the ligaments interposed between their peripheral surfaces.—Magnified 70 diameters.

Fig. 3. Longitudinal section of the terminal portion of a Dorsal Cirrhus; showing the claw articulated by the plane surface cut through at *a*, *a*, to the penultimate segment, and the movable articulation *b*, *b*, in which the fossæ for the lodgment of the ligament are much larger and deeper on the aboral side; at *c*, *c* is shown the central canal, which is continued into the cavity of the claw.—Magnified 70 diameters.

Fig. 4. Section of Centro-dorsal plate taken in a plane parallel to its flattened surface; showing at *b*, *b* the canals leading to the articular sockets.—Magnified 70 diameters.

PLATE XXXVI.

In this Plate are shown the First, Second, and Third *Radials*, and the First, Second, Third, Fourth, and Fifth *Brachials*, of *Antedon rosaceus*; their different aspects being designated (except in fig. 1) as follows:—

A, internal or proximal face.
B, external or distal face.
C, ventral or superior face.
D, dorsal or inferior face.
E, lateral face.

The following References are common to the entire series:—

a, *a*, Articular Ridges.
b, *b*, Fossæ for Interarticular Ligaments.
c, *c*, Muscular Fossæ.
d, *d*, Vertical Lamellæ.
e, Axial Canal.
f, *f*, Fossa for Elastic Ligament.
p, Articular Socket of Pinnule.
sg, Syzygy.

The magnifying power for all the Figures is 15 diameters.

Fig. 1. First Radial: on its internal aspect (B) are shown the apertures, *e*, *e*, of the two passages by which the Axial Canal originates, and the apertures, *g*, *g*, of the circular passage by which the axial canal of each Ray communicates with the canal of the Ray on either side; *h*, furrow between the prominent margins of the apertures *e*, *e*; *i*, *i*, smooth inclined faces, closely adherent to those of the First Radials on either side: A, external face.

Fig. 2. Second Radial.

Fig. 3. Third or Axillary Radial; *d'*, vertical ridge dividing the two articular faces.

Fig. 4. First Brachial.

Fig. 5. Second Brachial.

Fig. 6. Third Brachial, united in C, D, and E with the Fourth.

Fig. 7. Fourth Brachial.

Fig. 8. Fifth Brachial.

PLATE XXXVII.

Fig. 1. Portion of Skeleton of Arm of *Antedon rosaceus* about the middle of its length, seen from its dorsal aspect; the segments of the Arms and Pinnæ remaining united by their ligaments; *sg*, *sg*, syzygies.—Magnified 15 diameters.

Fig. 2. A similar portion somewhat nearer the base, seen from its ventral aspect, showing the Muscular fossæ and the situation of the articulations of the Pinnules.—Magnified 10 diameters.

Fig. 3. Basal portion of the skeleton of the Arms with their Pinnules, seen from their dorsal aspect:—r^3, Third Radial; 1–16, Brachial segments; *sg*, syzygies.—Magnified 10 diameters.

Fig. 4. A similar portion of the Skeleton of the Arms with the Pinnules removed, seen from their ventral aspect; showing the Interarticular Ligaments, the deep Muscular fossæ lying between the vertical ridges, the syzygies, *sg*, and the articular sockets of the Pinnules, *p*, *p*.—Magnified 15 diameters.

PLATE XXXVIII.

Fig. 1. Terminal portion of growing Arm; from a preparation in which the soft parts have been made transparent by soda, and the calcareous reticulation is shown by black-ground illumination.—Magnified 120 diameters.

Fig. 2. Portions of Arm near its termination, showing the nearly cylindrical form of its segments:—*c*, *c*, Muscular Fossæ; *p*, *p*, Articular sockets of Pinnules; *sg*, syzygies.—Magnified 15 diameters.

Fig. 3. Terminal portion of Pinnule, showing the hooks at its extremity, and the series of short segments below the last two.—Magnified 70 diameters.

Fig. 4. Terminal portion of Skeleton of Arm, with its Pinnules, seen from its dorsal aspect.—Magnified 15 diameters.

Fig. 5. Segment of Arm from about the middle of its length; A, distal face; B, proximal face; C, side view.—Magnified 15 diameters.

[N.B. Figures A and B have been drawn in an inverted position with reference to those in Plate XXXVI.; the *upper* margin being here the *dorsal*, and the *lower* the *ventral*].

Fig. 6. Portion of an Arm that has been broken at the first syzygy, with new arm sprouting from this.—Magnified 10 diameters.

Fig. 7. Single Arm growing from the Second Radial, r^2, the Third Radial being altogether deficient. The segments of this arm have their normal size and proportions; and the syzygies occur at their regular intervals.—Magnified 10 diameters.

Fig. 8. Calyx and basal portion of Arms of a specimen which seems at A to have lost one of its Rays at the junction of the First and Second Radials, a wew Ray and Arms having been produced on a smaller scale; whilst at B the Second

Brachial of one of the Arms acts as an axillary segment, bearing two small Arms.—Magnified 3½ diameters.

Fig. 9. Calyx and Basal portion of Arms of a specimen which seems, like the last, to have lost one of its Rays at the junction of the First and Second Radials, the Ray and Arms having been reproduced on a smaller scale.—Magnified 3½ diameters.

Fig. 10. Basal portion of Arms with the soft parts removed from their ventral surface, so as to show the disposition of the Muscles; r^3, Third Radial, with its pair of Muscles on either side connecting it with br^1 the First Brachial; between this and the Second Brachial, br^2, there is only ligamentous union; the next pair of muscles connects the Second with the Third Brachial, br^3; between the Third and the Fourth Brachial there is a syzygy, *sg*; and beyond this the muscles connect every segment with that which succeeds it, except where a syzygy intervenes. The small muscles connecting the segments of the Pinnules are also shown.—Magnified 15 diameters.

Fig. 11. Vertical Longitudinal Section of an Arm taken near its base, to show the arrangement of its Muscles, *m*, *m*, and its Ligaments, *l*, *l*, and the interruption of these at the syzygy, *sg*.—Magnified 15 diameters. (See also Plate XLIII. fig. 6.)

PLATE XXXIX.

Fig. 1. Group of Pentacrinoid larvæ of *Antedon rosaceus* in different stages:—A, showing the Basals, *b*, *b*, the circlet of First Radials, r^1, r^1, already complete, the rudimentary Second and Third Radials supported by this, and the circlet of Orals, *o*, *o*, alternating with these and resting on the First Radials; B, showing the incipient development of the Arms from the extremities of the Third Radials, the relative positions of the other parts being but little changed, and the Dorsal Cirrhi not having yet made their appearance (see Plate XLI. fig. 1 for a representation of the skeleton in this stage on a larger scale); C, showing the further development of the Arms, the incipient opening-out of the Calyx occasioned by the increased development of the First Radials, and the first appearance of the Dorsal Cirrhi; D, showing the first appearance of Pinnules at the extremities of the Arms, the further opening-out of the Calyx (bringing the vent into view), and the formation of the first whorl of Dorsal Cirrhi (see Plate XL.); E, showing the Pentacrinoid ready to assume its free condition, two rows of Dorsal Cirrhi being now completed, the Arms being considerably elongated by the addition of new segments, and several pairs of Pinnules being formed at their extremities.—Magnified 15 diameters.

Fig. 2. Skeleton of early Pentacrinoid larva, from a dried specimen, showing the mode in which the Calyx can be (in that stage) completely closed in by the folding together of the Orals, *o*, *o*.—Magnified 70 diameters.

Fig. 3. Skeleton of the Pentacrinoid larva represented in Fig. 1, C, showing two rudimentary segments of the Stem, the incipient development of the Dorsal Cirrhi, the Basals, *b*, *b*, the First, Second, and Third Radials, r^1,r^1, r^2,r^2, r^3,r^3, and the Anal, *a*, now being lifted up from between the First Radials.—Magnified 50 diameters.

PLATE XL.

Fig. 1. More enlarged view of a Pentacrinoid larva of *Antedon rosaceus*, in a stage nearly corresponding with that shown in Plate XXXIX. fig. 1, D, the nearest Ray having been removed so as to bring into view the Oral apparatus:—*cd*, Centro-dorsal plate, bearing two cirrhi, *cir*, *cir*, one rudimentary, another in an advanced stage of development; r^1,r^1, r^2,r^2, r^3,r^3, First, Second, and Third Radials; *o*, *o*, Orals, now completely separated from the Radials by the intervention of the membranous Perisome.—Magnified 60 diameters.

Fig. 2. Calyx of the same specimen seen from the other side, showing the Centro-dorsal plate, *cd*, bearing two cirrhi, *cir*, *cir*, one rudimentary, the other still retaining its rudimentary form, the First, Second, and Third Radials, r^1,r^1, r^2,r^2, r^3,r^3, and the Anal, *a*, now lifted out from between the First Radials by the development of the prominent Vent, *v*, to which it is attached.—Magnified 60 diameters.

PLATE XLI.

Fig. 1. Skeleton of Pentacrinoid at the time of the first development of the Arms, and before the first appearance of the dorsal cirrhi:—*b*, *b*, Basals; r^1, r^1, First Radials; *a*, Anal; r^2, r^2, Second Radials; *o*, *o*, Orals; r^3, r^3, Third Radials.—Magnified 100 diameters.

Fig. 2. Separated portions of the skeleton of the Calyx of a Pentacrinoid at the epoch of its detachment from the stem:—B, external and internal (dorsal and ventral) faces of Basals; R^1, external and internal faces of First Radials; R^2, external and internal faces of Second Radials; R^3, external and internal faces of Third Radials; A, Anal; C, ventral aspect of Centro-dorsal basin.—Magnified 100 diameters.

Fig. 3. Basals in process of conversion into Rosette:—*a*, dorsal aspect, showing partial absorption of first-formed lamella; *b*, another specimen turned a little to one side, showing the more complete absorption of the original lamella; *c*, *d*, ventral and dorsal aspects of a basal which has been nearly modelled by absorption and outgrowth into the form requisite to constitute the Rosette (Plate XXXIII. figs. 10, 11) by union with its fellows.—Magnified 100 diameters.

Fig. 4. Portion of the dried Stem of a young Pentacrinoid; showing the prominent annulus in the middle of each segment.—Magnified 70 diameters.

Fig. 5. Skeleton of the Calyx of a Pentacrinoid nearly ripe for detachment, as seen from its internal or ventral aspect, the centro-dorsal plate having been removed; *b*, *b*, Basals; r^1, r^1, First Radials.—Magnified 50 diameters.

Fig. 6. The same, as seen from its external or dorsal aspect:—*c*, central pore for the passage of the sarcodic axis through the Centro-dorsal plate; *b*, *b*, Basals; r^1, r^1, First Radials; r^2, r^2, Second Radials; r^3, r^3, Third or Axillary Radials; br^1, br^1, Brachials; *a*, Anal.—Magnified 50 diameters.

PLATE XLII.

Fig. 1. Incipient Rosette (see Plate XXXIII. figs. 10, 11) formed by the coalescence of the five altered Basals, in a young *Antedon*.—Magnified 120 diameters.

Fig. 2. Skeleton of Base of Calyx of young *Antedon*, seen from its internal or ventral side; showing the five basals (*b*) altered by endogenous growth, in preparation for the formation of the Rosette.—Magnified 100 diameters.

Fig. 3. Calyx of young *Antedon* just detached, seen from its dorsal side, showing five Cirrhi of the mature type and five of the rudimentary type, the Radial and Brachial plates, and the extension of the visceral disk as far as the Third Radial.—Magnified 25 diameters.

Fig. 4. Skeleton of the terminal portion of the Arms of a mature Pentacrinoid:—A, ventral aspect; B, dorsal aspect.—Magnified 100 diameters.

Fig. 5. Skeleton of the basal portions of the Arms of a mature Pentacrinoid:—A, ventral aspect; B, dorsal aspect.—Magnified 100 diameters.

Fig. 6. Skeleton of base of Calyx of young *Antedon*, seen from its ventral aspect; showing the five Basals grouped around *b*, and traversed by canals for the radiating cords of the sarcodic axis, of which a trunk enters each basal from the central space, and then subdivides into two branches, that pass into the two Radials between which the salient angle of the basal projects; thus each First Radial receives cords from two basals, and these are lodged in two Canals which coalesce into one towards its distal border, each of them having first become connected by a lateral branch with the like canal in its contiguous First Radial.—Magnified 70 diameters.

Fig. 7. The same viewed from its dorsal aspect, the Centro-dorsal plate having been removed; showing that the central space around *b* on the under side has been enlarged by the absorption of part of the original Basals, though it is still contracted, nearer the cavity of the Calyx, by the secondary endogenous growth: the system of Axial Canals is displayed as in the preceding figure.—Magnified 70 diameters.

PLATE XLIII.

Fig. 1. Portion of the Sarcodic Basis of the Skeleton of *Antedon rosaceus*, showing the granular glomeruli which occupy the interspaces of the calcareous reticulation.—Magnified 120 diameters.

Fig. 2. Transverse section of a decalcified Arm at a syzygy, showing the radiating extensions of sarcodic substance which occupy the grooves of the apposed calcareous segments.—Magnified 30 diameters.

Fig. 3. Ligamentous substance uniting the dorsal portions of the Brachial segments, magnified 70 diameters; 3A, portion of the same magnified 250 diameters.

Fig. 4. Muscular fibres, magnified 250 diameters, showing at *a* their enlarged terminations; A, separated fibres enlarged 870 diameters, showing nuclear (?) corpuscles, *a*, *b*, *c*.

Fig. 4. Vertical section of the decalcified skeleton of the basal portion of an Arm of *Antedon rosaceus*, showing the disposition of the Muscles and Ligaments:—*s*, *s*, *s*, bodies of the segments perforated by the Axial Canal, *a*, *a*, and connected by the Interarticular Ligaments, l^1, l^1, and the Elastic Ligaments, l^2, l^2; s^1, s^1, vertical lamellæ, the spaces between which are occupied by the Muscles *m*, *m*.—Magnified 55 diameters.

Fig. 4. Horizontal section of the decalcified skeleton of the basal portion of an Arm, passing through the Axial Canal *a*, *a*, and showing the alternating obliquity of the articulations, as shown in the disposition of the ligaments l^2, l^2; at *sg*, *sg*, are shown in transverse section the radiating extensions of sarcodic substance interposed between the syzygies, shown in fig. 2.—Magnified 35 diameters.

XXV. *On the Motion of a Rigid Body acted on by no external Forces.*

By J. J. SYLVESTER, *LL.D., F.R.S.*

Received April 26,—Read May 17, 1866.

As conveying an image of the motion of a rigid body acted on by no forces, POINSOT's well-known method of representation, whether by a rolling ellipsoid or a shifting cone, labours under an obvious imperfection; the *time* is not put in evidence by it. Thus when the ellipsoid, with which alone I intend here to deal, is employed, it is true that the proportional value of the velocity of rotation about the instantaneous axis is geometrically measured by the radius vector drawn from the fixed point to the invariable tangent plane, and so by a process of summation the time of passing from one position to another may be considered as inferentially determined; but there is nothing to convey to the senses, or to the mind's eye, a notion of the effect of this summation, and thus the relation of the most important element—the time—to the position of a free revolving body remains unexpressed. I shall begin with showing how by a slight addition to POINSOT's ideal kinematical apparatus this defect may be completely removed, and the time between successive positions conceived to register itself mechanically. As the property upon which this depends readily lends itself to a geometrical form of proof, I shall, in the first instance, follow that mode of investigation, as being the more germane to the matter in hand, reserving to a later point in the memoir the analytical demonstration; that is to say, assuming POINSOT's ellipsoid, and the law which connects the velocity with the position of the body, I shall show how the time may be, as it were, mechanically extracted and summed.

It will be well, then, in the first instance to recall some simple properties of confocal ellipsoids which I shall have occasion to employ. If parallel tangent planes be drawn to a system of confocal ellipsoids, it is well known (see Dr. SALMON'S great work on Surfaces, Art. 202, 1st edition, or Art. 184, 2nd edition) that the points of contact lie in a plane curve, and that this curve is an equilateral hyperbola. Since a concentric sphere with an infinite radius belongs to the system of confocal ellipsoids supposed, it follows that the point of intersection of the perpendicular from the centre of the ellipsoid upon the tangent planes with the plane at infinity, is a point in this curve, or, in other words, such perpendicular is contained in the plane of the hyperbola, and is an asymptote to the latter. The above is all that is required to establish the dynamical theorems necessary for my immediate purpose.

The revolving body being assumed to have moments of inertia A, B, C about the principal axes, the ellipsoid

$$Ax^2+By^2+Cz^2=1$$

rigidly connected with the body, and which may be termed its kinematical exponent, is supposed to have its centre fixed, and to turn with a purely rolling motion upon a plane in contact with it which contains the constant impulsive couple L, capable at each moment of time in any position into which the body has turned, of communicating to it from rest the motion which it then actually possesses. If we suppose that the angular velocity of rotation is always equal to LPR, where P is the length of the perpendicular distance of the fixed centre from the tangent plane, and R is the length of the radius vector drawn from it to the point of contact, the path and velocity of the motion of the body in rigid connexion with the ellipsoid is completely represented; this is POINSOT'S theorem stated in its complete form.

To fix the ideas, let us consider the invariable plane to be horizontal; if we were to apply a second plane parallel to the former fixed one, and also touching the ellipsoid, this would in no respect affect the motion—the ellipsoid might be made to roll between the two planes instead of rolling upon the under one alone; but if we were arbitrarily to alter the form of the upper part of the surface, the motion of rolling would in general be no longer possible; the only motion that could take place would be that of swinging round the vertical axis perpendicular to the two planes. In order that the ellipsoid may be able to roll as well as to swing, a certain geometrical condition must be satisfied, viz., the plane passing through the radius vector from the centre O to R, the point of contact with the given plane, and through the vertical perpendicular in question POp, must contain the point of contact r of the upper surface with the upper plane; for then, and then only, the rotation about OR may be resolved into two rotations about Or, Op respectively, and the ellipsoid whilst it rolls about OR, will be swinging round Op [or it may obviously at the same time be rolling and swinging (the latter in unequal degrees) upon each of the parallel tangent planes]; if this condition were not fulfilled, the ellipsoid, in the act of rolling upon the lower plane according to the direction of its motion, would either quit the upper one or tend to force it upwards; but as the upper, like the lower plane is supposed to be at a fixed distance from the centre, this tendency would be resisted, and thus the supposed motion of rolling upon the lower plane without quitting contact with the upper one could not be realized.

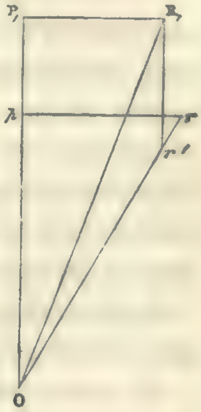
The condition that OR, POp, Or shall lie on one plane, we have seen will be fulfilled if the upper surface be a portion of an ellipsoid confocal with the lower one, and in that case the body may remain continually in contact with both planes whilst it rolls on the lower one; and we have thus a complete solution of the kinematical problem of determining what form must be given to the upper part of a body, the lower portion of whose surface is ellipsoidal, in order that it may be able to roll as well as swing between, and in contact with, two parallel fixed planes.

Call, then, the squared semiaxes of the lower surface a^2, b^2, c^2, and those of the upper one $a^2-\lambda$, $b^2-\lambda$, $c^2-\lambda$, and let us proceed to calculate the respective values of the two rotations about Op, Or equivalent to the single rotation LPR about OR.

In PO, RO produced set off OP_1, OR_1 equal to OP, OR, and draw $R_1 r_1$ parallel to

Op, and rp perpendicular to Op, and make $Or=r$, $Op=p$; then by virtue of what has been remarked above, r, R_1 lie in a hyperbola, of which OpP_1 is an asymptote, and the rotation about the instantaneous axis OR is represented by $L.P.OR_1$, and may be resolved into $L.P.Or'$ about Or' and $L.P.r'R_1$ about Op.

Fig. 1.



But

$$L.P.Or'=L.P.r.\frac{Or'}{Or}=L.r.P.\frac{P_1R_1}{p\,r}=L.r.P.\frac{Op}{OP_1}=L.r.p,$$

and

$$\begin{aligned}L.P.R_1r'&=L.P(OP_1-P_1R_1\tan r_1Op)\\&=L.P\left(OP_1-P_1R_1\frac{Op}{pr}\right)\\&=L.P\left(P-p\frac{p}{P}\right)\\&=L(P^2-p^2)=L\lambda;\end{aligned}$$

for if α, β, γ be the angles which OP, Op make with the axes of the ellipsoid,

$$\begin{aligned}P^2&=a^2(\cos\alpha)^2+b^2(\cos\beta)^2+c^2(\cos\gamma)^2,\\p^2&=(a^2-\lambda)(\cos\alpha)^2+(b^2-\lambda)(\cos\beta)^2+(c^2-\lambda)(\cos\gamma)^2,\\P^2-p^2&=\lambda\{(\cos\alpha)^2+(\cos\beta)^2+(\cos\gamma)^2\}=\lambda.\end{aligned}$$

Observing, then, that the motion has been resolved into a variable rotation Lpr about Or, and a uniform rotation $L\lambda$ about Op, and that accordingly the motion of a free body whose moments of inertia are as $\frac{1}{a^2}$; $\frac{1}{b^2}$; $\frac{1}{c^2}$ differs only by the uniform rotation $L\lambda$ from that of another one whose moments of inertia are as $\frac{1}{a^2-\lambda}$; $\frac{1}{b^2-\lambda}$; $\frac{1}{c^2-\lambda}$, we derive the following theorem:—

If the reciprocals of each of the moments of inertia of any number of rigid bodies B, B_1, B_2, B_3, … *differ from one another by constant quantities, say those of the second, third, fourth, &c., from those of the first by* λ_1, λ_2, λ_3, …, *and these bodies be arranged with their corresponding principal axes parallel and be set in motion by an impulsive couple* L *given in magnitude and direction, then, after the lapse of any interval of time* t, *the principal axes of all the bodies will remain equally inclined to the axis of the given couple, and moreover the parallelism of the axes may be restored by turning* B_1, B_2, B_3, … *about the axis of the couple through angles proportional to the time, viz.* $L\lambda_1t$, $L\lambda_2t$, $L\lambda_3t$, … *respectively.*

It may be further noticed that if at any moment of time ω, ω' are the angular velocities of B, B_1 about their respective instantaneous axes,

$$\begin{aligned}\omega^2-\omega_1^2&=L^2(P^2.R^2-p^2.r^2)\\&=L^2\left(P^2(R^2-P^2)-p^2(r^2-p^2)\right)+L^2(P^4-p^4)\\&=L^2\lambda^2(P^2+p^2),\end{aligned}$$

i. e. the difference between the squared velocities of any two bodies of the set is constant throughout the motion.

The above is a theory of rigid bodies whose kinematical exponents are confocal ellipsoids, and it has been shown that the motion of the whole set of bodies thus related, both as regards position and velocity, is completely determined when we know the motion of any one of them. It will hereafter appear from the analytical treatment of the subject that an analogous theorem applies to bodies whose kinematical exponents, instead of being confocal, are what may be termed contrafocal ellipsoids; ellipsoids, that is to say, the sums instead of the differences of whose squared axes are the same in all three directions.

By turning an ellipse through 90° round its centre we obtain a contrafocal ellipse; and contrafocal ellipsoids will be those all of whose principal sections are contrafocal.

To every infinite series of confocal ellipsoids there will correspond another such series, each ellipsoid of one series being contrafocal to each of the other, and it may very easily be seen that no two ellipsoids taken respectively out of the two opposite series can be obtained from each other by a mere change of place, as is the case with contrafocal ellipses; so in the instance of binary covariants and contravariants, any such can be converted into each other by the simple interchange of x, y with $y, -x$, but no such or similar commutability exists between covariants and contravariants of the ternary species. It may be here convenient to notice that the kinematical exponent (or momental ellipsoid) of a given uniform ellipsoid is not the ellipsoid itself, but the *reciprocal* of the contrafocal ellipsoid whose squared semiaxes are $\lambda-a^2$, $\lambda-b^2$, $\lambda-c^2$, where $\lambda=a^2+b^2+c^2$.

It is now clear how the time of passage from one position to another is susceptible of mechanical measurement. Let the upper part of POINSOT's ellipsoid, whose semiaxes are a, b, c, be pared away until it assumes the form of a segment of an ellipsoid whose squared semiaxes are $a^2-\lambda$, $b^2-\lambda$, $c^2-\lambda$; let the linear surface be in contact with a rough plane absolutely fixed, whilst its upper surface is so with a parallel *plate* not absolutely fixed, but capable of turning round an axis perpendicular to the two planes, and which if produced would pass through the centre of the ellipsoid. Then, when by the hand or any mechanical contrivance the body is made to spin like a sort of top upon the lower plane, it will also spin upon the *plate* above, and at the same time by the friction drive it round the vertical axis; the angle of rotation round this axis will give the exact measure of the time which the *free* body ideally associated with the ellipsoid would occupy in passing from one position to another. If this angle (which of course may be made to register itself by the motion of a hand upon a fixed dial-plate immediately over the rotating one which carries the index) be called φ, the time in question will be $\frac{\varphi}{L\lambda}$, where it is particularly deserving of notice that the denominator $L\lambda$ is independent of the initial position of the body; hence by supposing the plane and rotating-plate to be capable by a preliminary adjustment of being shifted to any required distance from one another, the ellipsoid may be started from any position we please, and the value of the divisions of the dial-plate which register the time will remain invariable.

The greater the value of λ which measures the degree of divergency of the two juxtaposed surfaces, the larger will be the divisions representing a given quantity of time; and there is no impediment to λ receiving its maximum value, which is the square of the least semiaxis (say c). The upper confocal surface then degenerates into a curve or hoop resting upon and driving before it the rotating-plate. This gives precision to the form to be assigned to the upper surface. Again, as regards the lower surface, whose form involves two parameters, viz. the ratios of the three axes, it will hereafter appear that we may without any loss of generality reduce it to depend upon a single parameter by assuming the reciprocal of the square of one of its axes equal to the sum of the reciprocals of the squares of the remaining two.

Hence with a single series of ellipsoids every possible kind of motion of a free rigid body may be completely represented both as regards time and place. Each ellipsoid with its confocal hoop may be regarded as complete in form, the former being imagined to consist of segments capable of being separated at will, so as to expose in succession each part as it is wanted of the interior hoop; and by an apparatus mechanically executable the motion may be followed without any break throughout the whole of one or any number of periods of revolution of the instantaneous axis.

Thus, then, the time of rotation of a free body may be kinematically determined. It may also, and even more simply, be measured off by direct observation of the time which a uniform ellipsoid spinning with its centre fixed upon an indefinitely rough plane occupies in passing from one position to another. To establish this somewhat remarkable law, let us consider the general case when the moments of inertia of the rolling ellipsoid have any values A, B, C. The resultant of the pressure and friction which coerce the ellipsoid to follow its actual path is a force always meeting the axis of instantaneous rotation, and giving rise therefore to an impressed couple whose axis is perpendicular to the former one. This being the case, and the ellipsoid subject to no other external force, its *vis viva* will be constant for just the same reason as the *vis viva* is so in the case of a system of particles connected in any manner, as by strings, whether elastic or inelastic, dragging each other along one or more surfaces, and acted on by no other forces except the reactions exerted by such surface or surfaces.

To render this perfectly clear, let $\upsilon_1\upsilon_2\upsilon_3$ denote the angular velocities of the rotating body about its principal axes; λ, μ, ν the angles between these axes and the instantaneous axis; J the magnitude of the couple produced by a force meeting the axis of rotation, then by EULER'S equations, we have

$$\mathrm{A}\frac{d\upsilon_1}{dt}-(\mathrm{B}-\mathrm{C})\upsilon_2\upsilon_3=\mathrm{J}\cos\lambda,$$

$$\mathrm{B}\frac{d\upsilon_2}{dt}-(\mathrm{C}-\mathrm{A})\upsilon_1\upsilon_3=\mathrm{J}\cos\mu,$$

$$C\frac{d\upsilon_3}{dt}-(A-B)\upsilon_1\upsilon_2=J\cos\nu;$$

also

$$\cos\lambda\upsilon_1+\cos\mu\upsilon_2+\cos\nu\upsilon_3=0.$$

Hence

$$A\upsilon_1 d\upsilon_1+B\upsilon_2 d\upsilon+C\upsilon_3 d\upsilon_3=0,$$

and

$$A\upsilon_1^2+B\upsilon_2^2+C\upsilon_3^2=K,$$

a constant, as was to be proved.

In the case actually under consideration, if ω_1, ω_2, ω_3 are the angular velocities of the associated free body, and τ the time corresponding to t, so that dt, $d\tau$ are the intervals of time of the rolling and the free body undergoing the same infinitesimal angular displacement of position, we have

$$\upsilon_1=\varrho\omega,\quad \upsilon_2=\varrho\omega,\quad \upsilon_3=\varrho\omega_3,$$

and

$$dt=\frac{\delta\tau}{\varrho}.$$

Hence

$$\varrho^2=\frac{K}{A\omega_1^2+B\omega_2^2+C\omega_3^2};$$

so that using the notation in ordinary use for the motion of a free body,

$$dt=\frac{d\tau}{\varrho}=\frac{\omega d\omega\sqrt{A\omega_1^2+B\omega_2^2+C\omega_3^2}}{\sqrt{(\omega^2-e_1)(\omega^2-e_2)(\omega^2-e_3)}},$$

and thus the time t of the rolling ellipsoid is known as an elliptic function in terms of ω^2.

Furthermore, by the well-known equations of *vis viva* and conservation of areas applied to the free body whose kinematical exponent is the ellipsoid with semiaxes a, b, c, i. e. whose moments of inertia may be denoted by $\frac{1}{a^2}$, $\frac{1}{b^2}$, $\frac{1}{c^2}$, we have

$$\frac{\omega_1^2}{a^2}+\frac{\omega_2^2}{b^2}+\frac{\omega_3^2}{c^2}=M,$$

$$\frac{\omega_1^2}{a^4}+\frac{\omega_2^2}{b^4}+\frac{\omega_3^2}{c^4}=L^2.$$

Consequently if A, B, C are respectively representable by

$$\frac{\lambda}{a^4}+\frac{\mu}{a^2},\quad \frac{\lambda}{b^4}+\frac{\mu}{b^2},\quad \frac{\lambda}{c^4}+\frac{\mu}{c^2},$$

the multiplicator of $\omega d\omega$ is the numerator of the expression above given for dt, becomes a constant, viz. $\lambda L^2+\mu M$. But this is the case when the density of the ellipsoid is uniform; for then

$$A:B:C::b^2+c^2:c^2+a^2:a^2+b^2,$$

and the determinant

$$\begin{vmatrix} \frac{1}{a^2}; & \frac{1}{b^2}; & \frac{1}{c^2} \\ \frac{1}{a^4}; & \frac{1}{b^4}; & \frac{1}{c^4} \\ b^2+c^2; & c^2+a^2; & a^2+b^2 \end{vmatrix} \quad \text{i. e. } \frac{1}{a^4b^4c^4}\Sigma(a^2-b^2)(a^2+b^2)=0.$$

In fact it is easily seen that

$$b^2+c^2=-\frac{a^2b^2c^2}{a^4}+\frac{b^2c^2+c^2a^2+a^2b^2}{a^2},$$

$$c^2+a^2=-\frac{a^2b^2c^2}{b^4}+\frac{b^2c^2+c^2a^2+a^2b^2}{b^2},$$

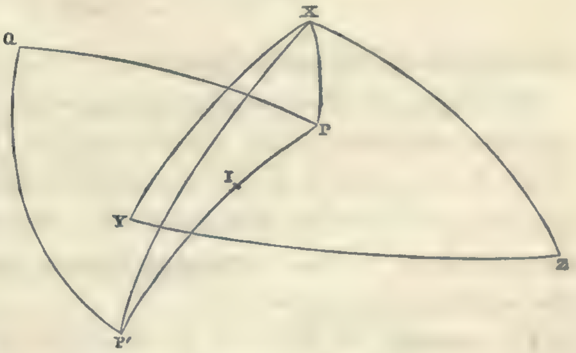
$$a^2+b^2=-\frac{a^2b^2c^2}{c^4}+\frac{b^2c^2+c^2a^2+a^2b^2}{c^2}.$$

Hence any uniform ellipsoid, with its centre fixed, compelled by friction to roll on a rough horizontal plane will move precisely like a free body with properly assigned moments of inertia acted on by no external forces, as was to be proved. We see from what has been shown above that a uniform ellipsoid whose semiaxes are a, b, c, and which rolls on a rough horizontal plane, will keep pace with the motion of a uniform free ellipsoid, provided that the moments of inertia of the latter are in the ratio of $\frac{1}{a^2}:\frac{1}{b^2}:\frac{1}{c^2}$, *i. e.* provided its axes are in the proportion of

$$\sqrt{\frac{1}{b^2}+\frac{1}{c^2}-\frac{1}{a^2}}:\sqrt{\frac{1}{c^2}+\frac{1}{a^2}-\frac{1}{b^2}}:\sqrt{\frac{1}{a^2}+\frac{1}{b^2}-\frac{1}{c^2}},$$

and thus the relative rate of motion of the rolling ellipsoid will not be affected if an interior ellipsoid whose axes are in the proportions above written is entirely removed or its density altered in any ratio. The internal ellipsoid will in fact move precisely as if it were free and detached from the surrounding crust, and might be annihilated without affecting the motion of the latter, in analogy with the well-known fact that any weight at the centre of oscillation of a compound pendulum may be abstracted without affecting its motion.

Fig. 2.



The theories of the free body and of the ellipsoid constrained by pressure and friction to follow its path, and which has been proved above to keep exact pace with it, are so interwoven that it would be unsatisfactory to leave the theory of the latter incomplete in any point, and I shall therefore proceed to calculate the value of the pressure and friction corresponding to any position of the rolling body. On a sphere described about the fixed point, let P and I denote the position of the instantaneous axis of rotation, and the perpendicular to the fixed plane respectively. The pole of the friction couple will be denoted by a point P′ in the plane of PI distant by a quadrant from P, for its plane passes through P and through Q the pole of PI, and the pole of the pressure couple will obviously lie at Q itself. Let X, Y, Z mark in the sphere the positions of the principal axes.

Then XPP′ being a quadrantal triangle,

$$\cos \mathrm{XP}' = \sin \mathrm{XP} \cos \mathrm{XPI} = \frac{1}{\sin \mathrm{PI}} (\cos \mathrm{XI} - \cos \mathrm{XP} \cos \mathrm{PI})$$

$$= \frac{1}{\sin \mathrm{PI}} \left(\frac{\omega_1}{a^2 \mathrm{L}} - \frac{\omega_1}{\omega} \frac{\mathrm{M}}{\mathrm{L}\omega} \right) = \frac{\omega_1}{\mathrm{L} \sin \mathrm{PI}} \left(\frac{1}{a^2} - \frac{\mathrm{M}}{\omega^2} \right),$$

where

$$\omega^2 = \omega_1^2 + \omega_2^2 + \omega_3^2.$$

Again, for greater simplicity, making $\varrho = \mathrm{I}$, *i. e.* considering the motions of the rolling body and the free nucleus to absolutely coincide in time, we have from the Eulerian equations,

$$\mathrm{J} \cos \lambda = (b^2 + c^2) \frac{d\omega_1}{d\tau} + (b^2 - c^2) \omega_2 \omega_3$$

$$= \frac{c^2 - b^2}{b^2} (a^2 b^2 + a^2 c^2 - b^2 c^2) \omega_2 \omega_3.$$

Hence if [F] be the couple due to F the friction force,

$$[\mathrm{F}] = \Sigma(\mathrm{J} \cos \lambda \cos \mathrm{XP}') = \frac{\omega_1 \omega_2 \omega_3}{\mathrm{L} a^2 b^2 c^2 \sin \mathrm{PI} \omega^2} \Sigma (c^2 - b^2)(a^2 b^2 + a^2 c^2 - b^2 c^2)(\omega^2 - \mathrm{M} a^2)$$

$$= \frac{2(c^2 - b^2)(b^2 - a^2)(a^2 - c^2) \omega_1 \omega_2 \omega_3}{\mathrm{L} a^2 b^2 c^2 \sin \mathrm{PI}}$$

$$= \frac{2(c^2 - b^2)(b^2 - a^2)(a^2 - c^2) \omega_1 \omega_2 \omega_3 \omega}{a^2 b^2 c^2 \sqrt{\mathrm{L}^2 \omega^2 - \mathrm{M}^2}}.$$

And as the arm at which the friction acts, *i. e.* the distance of the fixed centre from the point of contact between the ellipsoid and the fixed plane is $\frac{\sqrt{\mathrm{M}}}{\mathrm{L}} \sec \mathrm{PI}$, *i. e.* $\frac{\omega}{\sqrt{\mathrm{M}}}$, we have

$$\mathrm{F} = 2 \frac{(c^2 - b^2)(b^2 - a^2)(a^2 - c^2) \omega_1 \omega_2 \omega_3}{a^2 b^2 c^2} \sqrt{\frac{\mathrm{M}}{\mathrm{L}^2 \omega^2 - \mathrm{M}^2}},$$

the mass of the ellipsoid throughout being treated as unity.

We might, in like manner, through the algorithm of spherical triangles, proceed to calculate the value of the pressure couple [P] which is equal to the sum of the components $\mathrm{J} \cos \lambda$, $\mathrm{J} \cos \mu$, $\mathrm{J} \cos \nu$ multiplied respectively by the sines of the perpendicular arcs dropped upon PI from X, Y, Z. But it will be obtained more expeditiously in its simplest form by first calculating J itself, the value of the entire couple, and then using the equation $[\mathrm{P}]^2 = \mathrm{J}^2 - [\mathrm{F}]^2$.

For brevity, in place of a^2, b^2, c^2, ω^2, L^2 write f, g, h, Ω, Λ respectively, and let $f + g + h = p$, $fg + gh + hf = q$, $fgh = r$. Then

$$\frac{\Omega_1}{f^2} + \frac{\Omega_2}{g^2} + \frac{\Omega_3}{h^2} = \Lambda,$$

$$\frac{\Omega_1}{f} + \frac{\Omega_2}{g} + \frac{\Omega_3}{h} = \mathrm{M},$$

$$\Omega_1 + \Omega_2 + \Omega_3 = \Omega.$$

So that if $(f-g)(g-h)(h-f)=\zeta$, and $\varkappa=\frac{fgh}{\zeta}$,

$$\Omega_1=\varkappa\frac{h-g}{h^2g^2}\{\Omega-(g+h)\mathrm{M}+gh\Lambda\},$$

$$\Omega_2=\varkappa\frac{g-f}{f^2h^2}\{\Omega-(h+f)\mathrm{M}+hf\Lambda\},$$

$$\Omega_3=\varkappa\frac{h-g}{g^2f^2}\{\Omega-(f+g)\mathrm{M}+fg\Lambda\}.$$

Hence

$$(\Lambda\Omega-\mathrm{M}^2)[\mathrm{F}]^2=-4\Omega^4+(8p\mathrm{M}-4q\Lambda)\Omega^3+\big((4p^2+4q)\mathrm{M}^2-(4pq+12r)\mathrm{M}\Lambda+4pr\Lambda^2\big)\Omega^2$$
$$+\big((4pq-4r)\mathrm{M}^3-(4q^2+4pr)\mathrm{M}^2\Lambda+8qr\mathrm{M}\Lambda^2-4r^2\Lambda^3\big)\Omega.$$

Also from the Eulerian equations,

$$\mathrm{J}^2=\Sigma\frac{(g-h)^2}{g^2h^2}(fg+fh-gh)^2\Omega_2\Omega_3$$
$$=\frac{1}{\zeta}\Sigma\{(g-h)(fg+fh-gh)^2\mathrm{N}_1\},$$

where

$$\mathrm{N}_1=\Omega^2-(2f+g+h)\mathrm{M}\Omega+(fg+fh)\Lambda\Omega+(f^2+fg+fh+gh)\mathrm{M}^2$$
$$-\big(f^2(g+h)+2fgh\big)\mathrm{M}\Lambda+f^2gh\Lambda^2.$$

But

$$\Sigma(g-h)(fg+fh-gh)^2=4\Sigma(g^3h^2-g^2h^3)-4(fg+fh+gh)\Sigma(g^2h-h^2g)=0,$$

$$\Sigma(g-h)(fg+fh-gh)^2(2f+g+h)=\Sigma(fg-fh)(fg+fh-gh)^2=4\Sigma(fg-fh)g^2h^2=-4fgh\zeta,$$

$$\Sigma(g-h)(fg+fh-gh)^2(fg+fh)=-\Sigma gh(g-h)(fg+fh-gh)^2=$$
$$-(f^2g^2+f^2h^2+g^2h^2)\Sigma gh(g-h)+2fgh\Sigma gh(g^2-h^2)=\big((f^2g^2+f^2h^2+g^2h^2)-2fgh(f+g+h)\big)\zeta,$$

$$\Sigma(g-h)(fg+fh-gh)^2(f^2+fg+fh+gh)=\Sigma f^2(g-h)(fg+fh-gh)^2$$
$$=\Sigma(fg+fh+gh)^2f^2(g-h)=-(fg+fh+gh)^2\zeta,$$

$$\Sigma(g-h)(fg+fh+gh)^2\big(f^2(g+h)+2fgh\big)=\Sigma(f^2g^2-f^2h^2)(fg+fh-gh)^2$$
$$=-4(fg+fh)\Sigma gh(f^2g^2-f^2h^2)=-4fgh(fg+fh+gh)\zeta,$$

$$\Sigma(g-h)(fg+fh-gh+gh)^2f^2gh=fgh\Sigma(fg-fh)(fg+fh-gh)^2=-4f^2g^2h^2\zeta.$$

Hence

$$\mathrm{J}^2=\big(4r\mathrm{M}+(q^2-4pr)\Lambda\big)\Omega-(q\mathrm{M}-2r\Lambda)^2,$$

and

$$(\Lambda\Omega-\mathrm{M}^2)\mathrm{J}^2=\big(4r\mathrm{M}\Lambda+(q^2-4pr)\Lambda^2\big)\Omega^2-\big(4r\mathrm{M}^3+(2q^2-4pr)\mathrm{M}^2\Lambda-4qr\mathrm{M}\Lambda^2+4r^2\Lambda^3\big)\Omega$$
$$+\mathrm{M}^2(q\mathrm{M}-2r\Lambda)^2.$$

Hence

$$(\Lambda\Omega-\mathrm{M}^2)[\mathrm{P}]^2=(\Lambda\Omega-\mathrm{M}^2)\mathrm{J}^2-(\Lambda\Omega-\mathrm{M}^2)[\mathrm{F}]^2$$

$$=4\Omega^4-(8p\mathrm{M}^2-4q\Lambda)\Omega^3+\big((4p^2+4q)\mathrm{M}^2-(4pq+8r)\mathrm{M}\Lambda+q^2\Lambda^2\big)\Omega^2$$

$$-\big(4pq\mathrm{M}^3-(2q^2-8pr)\mathrm{M}^2\Lambda+4qr\mathrm{M}\Lambda^2\big)\Omega+\mathrm{M}^2(q\mathrm{M}-2r\Lambda)^2.$$

Hence

$$[\mathrm{P}]=\frac{2\Omega^2-(2p\mathrm{M}-q\Lambda)\Omega+\mathrm{M}(q\mathrm{M}-2r\Lambda)}{\sqrt{\Lambda\Omega-\mathrm{M}^2}};$$

and as the arm at which this couple acts is

$$\sqrt{\frac{\omega^2}{\mathrm{M}}-\frac{\mathrm{M}}{\mathrm{L}^2}},\ \ i.\,e.\ \sqrt{\frac{\Lambda\Omega-\mathrm{M}^2}{\mathrm{M}\Lambda}},$$

the pressure

$$\mathrm{P}=\frac{2\Omega^2-(2p\mathrm{M}-q\Lambda)\Omega+(q\mathrm{M}^2-2r\mathrm{M}\Lambda)}{\Lambda\Omega-\mathrm{M}^2}.$$

If we call the constant perpendicular from the centre and the radius vector to the point of contact h and l respectively, and substitute for $\frac{\Omega}{\Lambda}$, $\frac{\mathrm{M}}{\Lambda}$ their respective values h^2l^2, h^2, we may express $\frac{\mathrm{F}}{\mathrm{P}}$ as a function of h, l, and making this a maximum in respect to l, the least sufficient value of the coefficient of friction necessary to ensure rolling may be deduced in terms of the quantities $\frac{a}{h}$; $\frac{b}{h}$; $\frac{c}{h}$.

Also if θ denote the angle between the axis of the couple J and the pole of the plane PI, we have

$$(\cos\theta)^2=\frac{[\mathrm{P}]^2}{[\mathrm{J}]^2}=\frac{2h^4l^4-(2ph^2-q)h^2l^2+(qh^4-2rh^2)^2}{(h^2l^2-h^4)\big(4rh^2+(q^2-4pr)h^2l^2-(qh^2-2r)^2\big)},$$

or

$$\cos\theta=\frac{h\big(2h^2l^4-(2ph^2-q)l^2+(qh^2-2r)\big)}{\sqrt{l^2-h^2}\sqrt{(4rh^2+q^2-4pr)h^2l^2-(qh^2-2r)^2}}.$$

It has been already seen how, by the method of confocal ellipsoids, the number of constants entering into the question of the rotation of a rigid body about its centre of gravity has virtually been reduced by a unit; to render this important theory complete, and to give it the fullest extension of which it is capable, a corresponding dynamical theory of contrafocal ellipsoids remains to be developed, and might undoubtedly be discussed by analogous geometrical methods; but it will be found more expedient to take up the subject afresh from a purely analytical point of view, and then the theory will present itself in all its completeness under a single aspect.

Calling α, β, γ the angles which the invariable axis makes with the principal axes of the rotating body, we have the well-known equations

$$\cos\alpha=\frac{\mathrm{A}\omega_1}{\mathrm{L}},\ \ \cos\beta=\frac{\mathrm{B}\omega_2}{\mathrm{L}},\ \ \cos\gamma=\frac{\mathrm{C}\omega_3}{\mathrm{L}}$$

(immediate deductions from the self-obvious principle of the constancy of the couple competent at any instant to communicate to the rotating body the motion it is then actually endued with, conjoined with the geometrical property of the principal axes that the moment in respect to any one of them of the momenta of the particles of the body due to rotation about either of the other two is zero).

Consequently from the principle of *vis viva*, i. e. from the equation

$$A\omega_1^2+B\omega_2^2+C\omega_3^2=M,$$

in addition to the equation

$$(\cos\alpha)^2+(\cos\beta)^2+(\cos\gamma)^2=1, \quad \ldots \ldots \ldots \quad (1)$$

we have the equation

$$\frac{(\cos\alpha)^2}{A}+\frac{(\cos\beta)^2}{B}+\frac{(\cos\gamma)^2}{C}=\frac{M}{L^2}, \quad \ldots \ldots \ldots \quad (2)$$

and the Eulerian system of equations*,

$$A\frac{d\omega_1}{dt}-(B-C)\omega_2\omega_3=0, \quad B\frac{d\omega_2}{dt}-(C-A)\omega_3\omega_1=0, \quad C\frac{d\omega_3}{dt}-(A-B)\omega_1\omega_2=0,$$

---

* To make this paper complete within itself so as to come within the comprehension of those who have no previous knowledge of the special problem which it treats, it seems desirable to indicate an elementary method of obtaining these ofttimes herein quoted equations.

1. Suppose no external forces in operation. Consider the effects of the three partial velocities ω_1, ω_2, ω_3 in succession as if the others were non-existent.

Referring to fig. 3, ω_1 tends to produce no motion about OY or OZ in the time dt, because the moments of the centrifugal forces about these axes, quantitatively represented by Σmzx, Σmzy respectively, are each zero by virtue of the geometrical definition of the principal axes.

Thus to each partial velocity in the time dt is due only a motion of rotation about its own axis. Hence if $d\gamma$ is the variation in γ due to ω_1,

$$d\gamma=ZZ'\cos YZI=\omega_1 dt\frac{\cos\beta}{\sin\gamma},$$

or

$$d\cos\gamma=\cos\beta\omega_1 dt.$$

Similarly as regards the variation of $\cos\gamma$ due to ω_2,

$$d\cos\gamma=-\cos\alpha\omega_2 dt.$$

Hence the total variation $d\cos\gamma=(\cos\beta\omega_1-\cos\alpha\omega_2)dt$,

$$i.\ e.\ \frac{C}{L}d\omega_3=\left(\frac{B\omega_2\omega_1}{L}-\frac{A\omega_1\omega_2}{L}\right)dt,$$

or

$$d\omega_3=\frac{B-A}{C}\omega_2\omega_1 dt,$$

with analogous equations for $d\omega_2$, $d\omega_1$.

When the impressed couples about OX, OY, OZ respectively are L, M, N, the variations in the angular velocities due to them being

$$\frac{Ldt}{A}, \quad \frac{Mdt}{B}, \quad \frac{Ndt}{C},$$

these quantities must be added to the values of $d\omega_3$, $d\omega_2$, $d\omega$ indicated above. We have thus the equations in question.

It may be as well also here to indicate in the fewest words the rationale of the ellipsoidal representation of the motion.

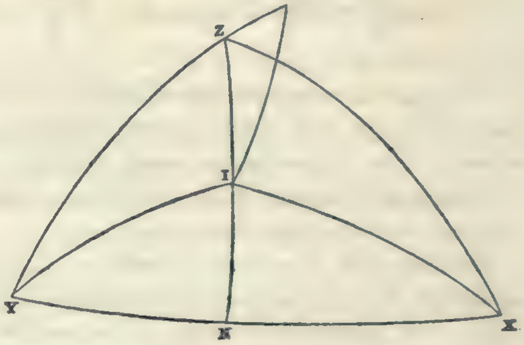
A, B, C being the principal moments of inertia, and $Ax^2+By^2+Cz^2=1$ the equation to the ellipsoid, the becomes

$$\left.\begin{array}{l}\dfrac{d\cos\alpha}{dt}-\mathrm{L}\left(\dfrac{1}{\mathrm{C}}-\dfrac{1}{\mathrm{B}}\right)\cos\beta\cos\gamma=0,\quad \dfrac{d\cos\beta}{dt}-\mathrm{L}\left(\dfrac{1}{\mathrm{A}}-\dfrac{1}{\mathrm{C}}\right)\cos\gamma\cos\alpha=0,\\ \qquad\dfrac{d\cos\gamma}{dt}-\mathrm{L}\left(\dfrac{1}{\mathrm{B}}-\dfrac{1}{\mathrm{A}}\right)\cos\alpha\cos\beta=0.\quad.\;.\;.\;.\;.\;.\;.\;.\;.\end{array}\right\}\quad.\;.\;.\;.\quad(3)$$

The above equations suffice to express the relations of the angles which the invariable line in space makes with fixed lines in the moving body to one another and to the time: to complete the solution it will be sufficient to express in terms of the time, or of any quantity dependent on the time, the position of any of the planes drawn through a principal axis and the invariable line.

The letters X, Y, Z, I retaining their previous signification, let ZZ′ represent the infinitesimal angular displacement of Z due to the rotation ω_1 about X in the time *dt*.

Fig. 3.



Then

$$\mathrm{ZIZ}'=\mathrm{ZZ}'\frac{\sin \mathrm{IZZ}'}{\sin \mathrm{IZ}'}=\mathrm{ZZ}'\frac{\cos \mathrm{NX}}{\sin \mathrm{IZ}}.$$

But

$$\frac{\cos \mathrm{NX}}{\cos \mathrm{NY}}=\frac{\cos \mathrm{IX}}{\cos \mathrm{IY}}=\frac{\cos\alpha}{\cos\beta},$$

or

$$\cos \mathrm{NX}=\frac{\cos\alpha}{\sqrt{(\cos\alpha)^2+(\cos\beta)^2}},$$

and

$$\sin \mathrm{IZ}=\sqrt{1-(\cos\gamma)^2}=\sqrt{(\cos\alpha)^2+(\cos\beta)^2}.$$

$$\text{Hence } \mathrm{ZIZ}'=\mathrm{L}\frac{\dfrac{(\cos\alpha)^2}{\mathrm{A}}dt}{(\cos\alpha)^2+(\cos\beta)^2}.$$

---

relation

$$\omega_1:\omega_2:\omega_3::\mathrm{A}\cos\alpha:\mathrm{B}\cos\beta:\mathrm{C}\cos\gamma$$

shows that the invariable line coincides in direction with the pedal to the radius vector drawn in the direction of the instantaneous axis.

2. Consequently the length of such pedal being

$$\frac{(\cos\alpha)^2}{\mathrm{A}}+\frac{(\cos\beta)^2}{\mathrm{B}}+\frac{(\cos\gamma)^2}{\mathrm{C}}$$

which is constant, a plane drawn at that constant length perpendicular to the invariable line touches the ellipsoid in every position into which it turns, and therefore the ellipsoid with its centre fixed rolls on such plane. This proves the identity of the two motions quâ space.

3. The moment of inertia in respect to the instantaneous axis being represented by the inverse squared length of the radius vector of the ellipsoid in the direction of that axis, the square root of the *vis viva* (a constant) is proportional to the angular velocity divided by the radius vector drawn to the point of contact, so that the former is proportional to the latter; this completes the representation by expressing through means of the ellipsoid the relation of the motion of the associated free body to time, or at all events it gives the law from which that relation may be extracted.

The above contains the whole sum, pith, and substance of Poinsot's ellipsoidal mode of representation.

Similarly, if ZIZ_1 be the angular displacement of the plane ZI measured in the same direction as before,

$$ZIZ_1=L\frac{\frac{(\cos\beta)^2}{B}dt}{(\cos\alpha)^2+(\cos\beta)^2},$$

and the rotation about Z causes no displacement of the plane in question. Hence if the horary angles, as they may be called, which measure the angular deviations of the planes XI, YI, ZI from a fixed meridian plane through I be called ξ, η, ζ, we have

$$\frac{d\xi}{dt}=L\frac{\frac{(\cos\beta)^2}{B}+\frac{(\cos\gamma)^2}{C}}{(\cos\beta)^2+(\cos\gamma)^2};\quad \frac{d\eta}{dt}=L\frac{\frac{(\cos\gamma)^2}{C}+\frac{(\cos\alpha)^2}{A}}{(\cos\gamma)^2+(\cos\alpha)^2};\quad \frac{d\zeta}{dt}=\frac{\frac{(\cos\alpha)^2}{A}+\frac{(\cos\beta)^2}{B}}{(\cos\alpha)^2+(\cos\beta)^2}\text{*}\quad . \quad . \quad (4)$$

If, now, preserving L constant we replace $\frac{1}{A}$, $\frac{1}{B}$, $\frac{1}{C}$, M by

$$\frac{1}{A}-\lambda;\ \frac{1}{B}-\lambda;\ \frac{1}{C}-\lambda;\ M-\lambda L^2,$$

the equations (1), (2), (3) remain unaltered, and the right-hand sides of equations (4)

---

* By combining this with the system of equations previously found, both η and ζ may readily be obtained under the form of elliptic functions of the third kind in terms of $\cos\gamma$, but $\eta-\zeta$ or the angle I in the quadrantal spherical triangle XIY of fig. 3 will also be expressible as a function of α, β, and therefore of γ. The comparison of the forms of $\eta-\zeta$ given by the two methods respectively, leads therefore to a theorem in elliptic functions; Professor CAYLEY has worked this out, and finds that it is the well-known theorem which expresses the dependence between two elliptic functions of the third order, the product of whose parameters is equal to the square of the modulus. I subjoin an extract from his letter, in which I have only introduced some slight changes in the lettering:—

"Writing

$$Ap^2+Bq^2+Cr^2=M,$$
$$A^2p^2+B^2q^2+C^2r^2=L^2,$$

your theorem is

$$\int\frac{M-Ap^2}{L^2-A^2p^2}dt-\int\frac{M-Bq^2}{L^2-B^2q^2}dt=\cos^{-1}(\ldots.)$$
$$=\tan^{-1}(\ldots.),$$

where

$$dt=-\frac{Cdr}{(A-B)pq}.$$

Whence expressing everything in terms of r, this is

$$\int\frac{F+Gr^2}{(1+nr^2)\sqrt{R}}dr-\int\frac{F_1+G_1r^2}{(1+n_1r^2)\sqrt{R}}dr=\tan^{-1}(\ldots.);$$

write for shortness,

$$AM-L^2=0,\quad BM-L^2=b,$$
$$B-C=\alpha,\quad C-\alpha=\beta,\quad A-B=\gamma.$$

Then we have

$$B\gamma q^2=a+CBr^2;\quad -A\gamma p^2=b-C\alpha r^2;$$

or if $r^2=-\frac{a}{C\beta}\ {}^2$,

$$B\gamma q^2=a(1-\theta^2);\quad -A\gamma p^2=b\left(1+\frac{a\alpha}{b\beta}\theta^2\right);$$

become each of them simply altered by the addition of the term $-\mathrm{L}\lambda$, which may be expressed by saying that the difference between the displacements at any moment of time of two bodies whose kinematical exponents are confocal ellipsoids, is equivalent to a displacement round the invariable line proportional to the time elapsed since the positions were coincident or parallel, as previously found by geometrical reasoning.

Again, if we replace $\frac{1}{\mathrm{A}}, \frac{1}{\mathrm{B}}, \frac{1}{\mathrm{C}}$, M by

$$\lambda-\frac{1}{\mathrm{A}};\ \lambda-\frac{1}{\mathrm{B}};\ \lambda-\frac{1}{\mathrm{C}};\ \lambda\mathrm{L}^2-\mathrm{M},$$

the equations (1), (2), (3) will remain unaltered, provided we write $180-\alpha$; $180-\beta$; $180-\gamma$ in place of α, β, γ, and the equations (4) will receive an augmentation of $\mathrm{L}\lambda$ on their right-hand sides, but remain otherwise unaltered, provided we substitute $-\xi$, $-\eta$, $-\zeta$ for ξ, η, ζ. Or again, we may state the same result without substituting for the angles of inclinations their supplements, but leaving them unaltered if we change the sign of L; showing that if two bodies whose kinematical exponents or momental ellipsoids are

---

so that using θ instead of r, the radical is

$$\sqrt{(1-\theta^2)(1-\varkappa^2\theta^2)},\quad \varkappa^2=-\frac{a\alpha}{b\beta},$$

$$\begin{aligned}\mathrm{L}^2-\mathrm{A}^2p^2&=\mathrm{L}^2+\frac{\mathrm{A}}{\gamma}(b-\mathrm{C}\alpha r^2)=\frac{1}{\gamma}(\mathrm{B}a-\mathrm{AC}\alpha r^2)\\&=\frac{\mathrm{B}a}{\gamma}\left(1+\frac{\mathrm{AC}\alpha}{\mathrm{B}a}\cdot\frac{a}{\mathrm{C}\beta}\theta^2\right)\\&=\frac{\mathrm{B}a}{\gamma}\left(1+\frac{\mathrm{A}\alpha}{\mathrm{B}\beta}\theta^2\right),\end{aligned}$$

$$\begin{aligned}\mathrm{L}^2-\mathrm{B}^2q^2&=\mathrm{L}^2-\frac{\mathrm{B}}{\gamma}(a+\mathrm{C}\beta r^2)=\frac{1}{\gamma}(-\mathrm{A}b-\mathrm{BC}\beta r^2)\\&=-\frac{\mathrm{A}b}{\gamma}\left(1-\frac{\mathrm{BC}\beta}{\mathrm{A}b}\cdot\frac{a}{\mathrm{C}\beta}\theta^2\right)\\&=-\frac{\mathrm{AB}}{\gamma}\left(1-\frac{\mathrm{B}a}{\mathrm{A}b}\theta^2\right).\end{aligned}$$

So that the form is

$$\int d\theta\frac{\mathrm{F}+\mathrm{G}\theta^2}{(1+n\theta^2)\sqrt{\Theta}}-\int d\theta\frac{\mathrm{F}_1+\mathrm{G}_1\theta^2}{(1+n_1\theta^2)\sqrt{\Theta}}=\ldots\ldots,$$

where

$$n=\frac{\mathrm{A}\alpha}{\mathrm{B}\beta},\quad n_1=-\frac{\mathrm{B}a}{\mathrm{A}b},\quad \varkappa^2=-\frac{a\alpha}{b\beta},$$

and thus

$$nn_1=-\frac{a\alpha}{b\beta}=\varkappa^2,$$

so that the relation is the known one between the two forms

$$\int\frac{d\theta}{(1+n\theta^2)\sqrt{\Theta}}\quad\text{and}\quad\int\frac{d\theta}{\left(1+\frac{\varkappa^2}{n}\theta^2\right)\sqrt{\Theta}}$$

with reciprocal parameters."

contrafocal, be set in a parallel position at rest, and are acted on by two equal and coaxial but contrary impulsive couples, their principal axes will continue throughout the motion to make equal but contrary angles with the invariable line, and will admit of being brought back to a position of parallelism by means of a rotatory displacement about the invariable line proportional to the time. Thus, leaving out of consideration this displacement, *correlated* solid bodies (as those may be termed whose kinematical exponents are confocal ellipsoids) may be made to move equally and similarly, and *contrarelated* ones (as we may term those whose kinematical exponents are contrafocal ellipsoids) equally and contrarily without the action of any external force. It will eventually be seen that there is a practical advantage in considering L as retaining the same sign in both cases, and throwing the contrariety of motion in the second case upon the change of the inclinations α, β, γ into their supplements.

Thus the motion of a body is arithmetically given when that of any other of the series of those to whose kinematical exponents its own is either confocal or contrafocal has been determined.

Alike for the two cases of con- and contra-focalism it will be convenient to disregard this uniform motion of rotation, treating it in the light merely of a correction*, so that the motions of all the bodies contained in either one series may be considered in regard to themselves as *coincident*, and as *supplemental* (in a sense that explains itself) in regard of the motions of the bodies belonging to the other series. I shall now show as a corollary from the above proposition that, with the above understanding, the motion of any rigid body may (subject to an unimportant exception that will be stated in its proper place) be made identical with that of one real indefinitely flattened disk, and supplemental to that of another. The case of a disk, it will be noticed, is that in which one of the principal moments of inertia becomes equal to the sum of the other two; in general these moments of inertia must not only be positive, but each must be not greater than the sum of the other two, as is the case with the lengths of the sides of a triangle; in the extreme case, when the body is reduced to but two dimensions, the greatest becomes equal to the sum of the other two, and conversely, when this is so, the body can only be of the form of a flat disk; the above is obvious when it is remembered that the moments of inertia are the sums of the three intrinsically positive quantities Σmx^2, Σmy^2, Σmz^2 taken two and two together. So also it is well to notice that the modular quantity $\frac{M}{L^2}$ in equation (2) is not absolutely arbitrary, but besides being essentially positive, is conditioned to lie between the least and greatest of the quantities $\frac{1}{A}$; $\frac{1}{B}$; $\frac{1}{C}$, since otherwise the quantities $(\cos\alpha)^2$; $(\cos\beta)^2$; $(\cos\gamma)^2$ in equations (1) and (2) could not all remain positive, and consequently such equations would not correspond to any real case of motion.

---

* The apparent motions of any two correlated or contrarelated bodies to two spectators standing respectively on the invariable plane of each may be made identical or similar, provided a certain uniform angular velocity be imparted to one of these planes.

Let A, B, C be arranged in order of magnitude, and suppose

$$\frac{1}{A_1}=\frac{1}{A}-\frac{1}{\mu},\quad \frac{1}{B_1}=\frac{1}{B}-\frac{1}{\mu},\quad \frac{1}{C_1}=\frac{1}{C}-\frac{1}{\mu},\quad \frac{M_1}{L^2}=\frac{M}{L^2}-\frac{1}{\mu},$$

and let μ be so determined as to make one of the quantities A_1, B_1, C_1 equal to the sum of the other two. Then

(1) Any imaginary value of μ must be neglected.

(2) Any value of μ which makes A_1, B_1, C_1 of different algebraical signs must be neglected.

(3) If μ, being real, makes A_1, B_1, C_1 all positive, these quantities will correspond to the moments of a real disk whose representative ellipsoid is confocal to that of the body whose moments of inertia A, B, C are given.

(4) If μ, being real, makes A_1, B_1, C_1 all negative, by taking $-A_1$, $-B_1$, $-C_1$, *i. e.* the reciprocals of $\frac{1}{\mu}-\frac{1}{A}$, $\frac{1}{\mu}-\frac{1}{B}$, $\frac{1}{\mu}-\frac{1}{C}$ as the new moments of inertia, we evidently shall have obtained a reduction to a disk of the supplemental or contrafocal kind.

In case (3) $M-\frac{L^2}{\mu}$, and in case (4) $\frac{L^2}{\mu}-M$ is to be substituted for M, so that the necessary condition of $\frac{L^2}{M}$ being intermediate between the greatest and least of the quantities A, B, C will continue to be fulfilled in the disk by $\frac{L^2}{M_1}$ remaining intermediate between the greatest and least of the quantities A_1, B_1, C_1.

Suppose $A_1+B_1=C_1$, then

$$\frac{A}{A-\mu}+\frac{B}{B-\mu}=\frac{C}{C-\mu},$$

or

$$(A+B-C)\mu^2+AB\mu+ABC=0.$$

The determinant (*i. e.* negative discriminant) of this equation is

$$AB(AB-CA-CB+C^2) \text{ or } AB(A-C)(B-C);$$

so that if C is the least or greatest moment of inertia, μ will have real values, but will be unreal if C is the mean moment of inertia.

Suppose now that $A_1+B_1=C_1$ for one value of μ, to find the values A', B', C' corresponding to the conjugate disk, we obtain from the above equation in μ, by substituting A_1, B_1, C_1 for A, B, C,

$$2A_1B_1\mu-A_1B_1C_1=0, \text{ or } \mu=-\frac{C_1}{2},$$

and accordingly

$$\frac{1}{A'}:\frac{1}{B'}::\frac{1}{A_1}-\frac{2}{A_1+B_1}:\frac{1}{B_1}-\frac{2}{A_1+B_1}::\frac{B_1-A_1}{2A_1}:\frac{A_1-B_1}{2B_1}::\frac{1}{A_1}:-\frac{1}{B_1}.$$

Hence if A_1, B_1 have the same signs, A', B' have opposite signs, and *vice versâ*, if A_1, B_1 have opposite signs A', B', and therefore A', B', C' have all the same signs for $C'=A'+B'$.

Consequently one and one only of each of the two solutions for disks drawn perpendicular respectively to the extreme principal axes, makes the three moments of inertia all of the same sign, and consequently each such solution leads either to a direct or supplemental reduction to the disk form.

Now, suppose that A, B, C being all of the same signs, A has become equal to B+C, so that the equation in μ becomes

$$2B\mu^2+2AB\mu+ABC=0,$$

or

$$\mu^2-A\mu+\frac{AC}{2}=0.$$

Let μ_1, μ' be the two values of μ from this equation, so that

$$\frac{1}{A_1}=\frac{1}{A}-\frac{1}{\mu_1},\quad \frac{1}{B_1}=\frac{1}{B}-\frac{1}{\mu_1},\quad \frac{1}{C_1}=\frac{1}{C}-\frac{1}{\mu_1},$$

$$\frac{1}{A'}=\frac{1}{A}-\frac{1}{\mu'},\quad \frac{1}{B'}=\frac{1}{B}-\frac{1}{\mu'},\quad \frac{1}{C'}=\frac{1}{C}-\frac{1}{\mu'},$$

and

$$A_1+B_1=C_1,\quad A'+B'=C'.$$

Then

$$\frac{1}{A_1}+\frac{1}{A'}=\frac{2}{A}-\left(\frac{1}{\mu_1}+\frac{1}{\mu'}\right)=\frac{2}{A}-\frac{2}{C}=2\left\{\frac{1}{B+C}-\frac{1}{C}\right\}=-\frac{2}{AC},$$

$$\frac{1}{A_1}\cdot\frac{1}{A'}=\frac{1}{A^2}-\left(\frac{1}{\mu_1}+\frac{1}{\mu'}\right)\frac{1}{A}+\frac{1}{\mu_1\mu'}$$

$$=\frac{1}{A^2}.$$

Hence if A, B, C have the positive sign, A_1 and A' are both negative, and if A, B, C have the negative sign, A_1 and A' are both positive; consequently, on the first supposition, the signs of one of the two systems A_1, B_1, C_1; A', B', C' will be all negative, and on the second supposition all positive. Hence one of the two reductions falls under case (3), *i. e.* is proper or direct, and the other under case (4), and is improper or supplemental. As nothing in nature exists in vain, it will presently be seen that the choice which is always possible between these two modes of reduction leads to an important simplification of the cases which arise in the problem of rotation, and that there need never be any room for doubt as to which of the two sorts of reduction should be employed in any specified problem.

The case of exception to which allusion has been made in anticipation, arises when two of the moments of inertia are equal; for then, supposing A, A_1, C to be the original moments of inertia, the new moments of inertia will be A_1, A_1, C_1; and since C_1 cannot be zero, we can only suppose $C_1=2A_1$; and making

$$\frac{1}{A_1}=\frac{1}{A}-\frac{1}{\mu},\quad \frac{1}{C_1}=\frac{1}{C}-\frac{1}{\mu},$$

the equation in μ becomes

$$\frac{2A}{A-\mu}=\frac{C}{C-\mu},$$

or

$$(2A-C)\mu=AC, \quad \mu=\frac{AC}{2A-C},$$

and

$$A_1=\frac{A\mu}{\mu-A}=\frac{AC}{2(C-A)}, \quad C_1=\frac{AC}{C_1-A};$$

so that the reduction will be proper or improper according as the unequal moment of inertia is greater or less than either of the equal ones.

A relation has been obtained geometrically in the commencement of this memoir between the squared velocities of any two dynamically equivalent bodies represented by confocal ellipsoids. To complete the theory, it is proper to find the exact nature of this relation when a given body has been reduced to a disk, whether by the direct or supplemental method.

First, in the case of direct reduction, using υ_1, υ_2, υ_3 for the angular velocities of the disk, and ω_1, ω_2, ω_3 for those of the associated body in corresponding positions about the principal axes, and υ, ω for the total angular velocities of the disk and body respecetively,

$$\upsilon_1=\frac{L}{A_1}\cos\alpha, \quad \upsilon_2=\frac{L}{B_1}\cos\beta, \quad \upsilon_3=\frac{L}{C_1}\cos\gamma,$$

$$\omega_1=\frac{L}{A}\cos\alpha, \quad \omega_2=\frac{L}{B}\cos\beta, \quad \omega_3=\frac{L}{C}\cos\gamma,$$

$$\frac{1}{A_1}=\frac{1}{A}-\lambda, \quad \frac{1}{B_1}=\frac{1}{B}-\lambda, \quad \frac{1}{C_1}=\frac{1}{C}-\lambda.$$

Hence

$$\omega^2=\Sigma\omega_1^2=\Sigma\left(\frac{L}{A_1}+L\lambda\right)^2(\cos\alpha)^2=\Sigma\upsilon_1^2+2L^2\lambda\Sigma\frac{(\cos\alpha)^2}{A_1}+L^2\lambda^2$$

$$=\upsilon^2+2L^2\lambda\frac{M}{L^2}+L^2\lambda^2,$$

or

$$\omega^2-\upsilon^2=\lambda L^2\left(\frac{2M}{L^2}+\lambda\right).$$

And again, in the case of supplemental reduction, using υ_1, υ_2, υ_3, υ for the partial and total angular velocities of the disk,

$$\upsilon_1=-\frac{L}{A_1}\cos\alpha, \quad \upsilon_2=-\frac{L}{B_1}\cos\beta, \quad \upsilon_3=-\frac{L}{C_1}\cos\gamma,$$

$$\frac{1}{A'}=\lambda-\frac{1}{A}, \quad \frac{1}{B'}=\lambda-\frac{1}{B}, \quad \frac{1}{C'}=\lambda-\frac{1}{C},$$

$$\omega^2=\Sigma\left(L\lambda-\frac{L}{A_1}\right)^2(\cos\alpha)^2=\upsilon^2-2L^2\lambda\frac{M}{L^2}+L^2\lambda^2,$$

or

$$\omega^2-\upsilon^2=\lambda L^2\left(-\frac{2M}{L^2}+\lambda\right);$$

showing that in both cases alike the differences between the squared velocity of the body and that of either its representative disks is constant throughout the motion, as might also have been predicted *à priori* from the form of the elliptic function connecting the time with the squared velocity. In the case of disk motion there is a distinctive feature which is deserving of notice. In this case we have

$$A\omega_1^2+B\omega_2^2+(A+B)\omega_3^2=M,$$

$$A^2\omega_1^2+B^2\omega_2^2+(A+B)\omega_3^2=L^2.$$

Hence

$$AB(\omega_1^2+\omega_2^2)=(A+B)M-L^2,$$

showing that the angular velocity with which the disk turns about a line in its own plane is constant throughout the motion, whilst the velocity about the axis perpendicular to its plane is continually varying, in the first particular agreeing with, and in the second differing from what takes place for a body of three dimensions with two of its principal moments of inertia equal.

It is easy to see how in the general case every conceivable motion of a body of any form may be tabulated and reduced to a table of treble entry, and how greatly the use of such tables may be facilitated, and seemingly distinct cases reduced to identity by aid of the twofold method of reduction above explained. Let us consider the case of a body whose principal moments of inertia are A, B, C, arranged in ascending order of magnitude.

We have seen that the quantity $\frac{M}{L^2}$ must always be intermediate between $\frac{1}{A}$ and $\frac{1}{C}$.

If the direct reduction be employed instead of $\frac{1}{A}$, $\frac{1}{B}$, $\frac{1}{C}$, $\frac{M}{L^2}$, we shall have

$$\frac{1}{A}-\lambda;\ \frac{1}{B}-\lambda;\ \frac{1}{C}-\lambda;\ \frac{M}{L^2}-\lambda,\ \text{say}\ \frac{1}{A_1};\ \frac{1}{B_1};\ \frac{1}{C_1};\ \frac{M_1}{L^2};$$

and if $\frac{M}{L^2}$ is intermediate between $\frac{1}{B}$ and $\frac{1}{C}$, $\frac{M_1}{L^2}$ will be intermediate between $\frac{1}{B_1}$ and $\frac{1}{C_1}$, where $C_1=A_1+B_1$.

On the other hand, if the supplemental method be employed,

$$\lambda-\frac{1}{A},\ \lambda-\frac{1}{B},\ \lambda-\frac{1}{C},\ \lambda-\frac{M}{L^2},\ \text{say}\ \frac{1}{C'},\ \frac{1}{B'},\ \frac{1}{A'},\ \frac{M'}{L^2},$$

where $C'=A'+B'$ will take the place of $\frac{1}{A}$, $\frac{1}{B}$, $\frac{1}{C}$; so that if $\frac{M}{L^2}$ is intermediate between $\frac{1}{A}$ and $\frac{1}{B}$, $\frac{M'}{L^2}$ will be intermediate between $\frac{1}{B'}$ and $\frac{1}{C'}$.

Hence by using the direct method of reduction in the case where $\frac{L^2}{M}$ is greater than B, and the supplemental method of reduction where $\frac{L^2}{M}$ is less than B, the original body can be always replaced by a disk of which A_1, B_1, A_1+B_1 are the new principal moments of inertia, L the given initial impulsive couple, M the new *vis viva*, and where the ascending order of the magnitudes is $\frac{1}{A+B}$, $\frac{M}{L^2}$, $\frac{1}{B}$, $\frac{1}{A}$, so that $\frac{BM}{L^2}$, $\frac{AM}{L^2}$ will be both of them less than unity. This reduction being effected when the motion of the disk is known, that of the associated body is given.

Calling the two parameters $\frac{BM}{L^2}$, $\frac{AM}{L^2}$, q_2, q_1[*] respectively, an inspection of the system of equations (1, 2, 3, 4) at pp. 767, 768 will show that the angles α, β, γ, ξ, η, ζ, ω are known, and may be registered in a table when $\frac{M}{L}t$, q_1, q_2 are given, the time t being reckoned from some determinate epoch, which must be so fixed as to be identical for the disk and the associated body[†]. We may assume as such epoch indifferently the moment when the axis of the disk has its maximum, or when it has its minimum inclination to the invariable line, *i. e.* when the quantity $(\cos\gamma)^2$ in the equations

$$\left.\begin{aligned}&(\cos\alpha)^2+(\cos\beta)^2+(\cos\gamma)^2=1,\\&\frac{(\cos\alpha)^2}{q_1}+\frac{(\cos\beta)^2}{q_2}+\frac{(\cos\gamma)^2}{q_1+q_2}=1\end{aligned}\right\}\dagger$$

---

[*] Calling A, B, C the original moments of inertia, it is important to notice that we have seen that no real distinction of motion arises from $\frac{M}{L^2}$ lying between $\frac{1}{A}$ and $\frac{1}{B}$ on the one hand, or between $\frac{1}{B}$ and $\frac{1}{C}$ on the other; the so-called two kinds of polhods and LEGENDRE's primary distinction of the problem into his cases (1) and (2) turn entirely upon this difference, but the two kinds of motion are convertible into one another (save as to the correction for the uniform displacement round the invariable line) by the theory of contra-relation. The real essential distinction of cases can only arise from particular values being assumed by q_1, q_2.

The quantities 0, q_1, q_2, 1, q_1+q_2 are written in natural ascending order.

The two *singular* cases are (A) when $q_1=q_2$, which is the case of two equal moments, (B) when $q_2=1$, which is LEGENDRE's 'Troisième Cas,' 'Cas très-remarquable," arts. 26, 27, corresponding to the instantaneous axis describing the so-called "separating polhod."

Besides these properly called singular cases, there are what may be termed special cases arising from sequences of two or of three terms in the above quinary scale becoming approximately equal, or *subequal*, in Mr. DE MORGAN's language, which relation may be denoted by the ordinary sign of equivalence.

Thus we shall have special cases when

$$q_1\equiv 0,\ \text{or}\ q_2\equiv q_1,\ \text{or}\ 1\equiv q_2,\ \text{or}\ q_1+q_2\equiv 1,$$

and double-special cases when

$$q_2\equiv q_1\equiv 0,\quad 1\equiv q_2\equiv q_1,\quad q_1+q_2\equiv 1\equiv q_2.$$

The last of these is of course tantamount to $1\equiv q_2$ with $q_1\equiv 0$. But even this table does not exhaust all the specially notable cases; for in the first of the double-special cases which corresponds to that of a body differing little from a sphere, we may again mark off as extra-double special the case where $\frac{q_1}{q_2}\equiv 0$, and also that where $\frac{q_1}{q_2}\equiv 1$.

It does not fall in with the plan of this paper to investigate these several cases, but they are probably all of them deserving of particular examination.

[†] We may express the motion in terms of the parameters q_1, q_2 as follows, writing x, y, z for $\cos\alpha$, $\cos\beta$, $\cos\gamma$:

$$\left.\begin{aligned}&x^2+y^2+z^2=1,\\&\frac{x^2}{q_1}+\frac{y^2}{q_2}+\frac{z^2}{q_1+q_2}=1,\end{aligned}\right\}\quad\ldots\ldots\ldots\ldots\ldots\ (1)$$

$$\frac{dz}{dt}=L\left(\frac{1}{A}-\frac{1}{B}\right)xy=\frac{M}{L}\left(\frac{1}{q_1}-\frac{1}{q_2}\right)xy,\quad\ldots\ldots\ldots\ldots\ (2)$$

$$d\zeta=L\frac{\frac{x^2}{A}+\frac{y^2}{B}}{1-z^2}dt=\frac{M}{L}\left(\frac{1-\frac{z^2}{q_1+q_2}}{1-z^2}\right)dt.\quad\ldots\ldots\ldots\ldots\ (3)$$

attains its maximum or minimum value; the equations being linear between $(\cos\alpha)^2$, $(\cos\beta)^2$, $(\cos\gamma)^2$, say between x, y, z, the extreme values of z of course correspond to the zero values of x and y respectively.

In using such tables of treble entry, we may suppose the initial angular velocities about the principal axes to be given, from which and the known moments of inertia the quantities L and M may be calculated, and then by the direct or supplemental method of reduction the value of λ and of the two parameters q_1, q_2 in the equivalent disk, each less than unity, found. 1st. If the reduction is direct—from the given inclination of the axis of the disk to the invariable line—the time t_0 from the epoch can be found by inspection, and then the entries corresponding to $t+t_0$ will give the inclinations at the end of the time t of the principal axes to the invariable line, and the position of the node defined as the intersection of the invariable plane with the plane through the invariable line and the axis of the disk (which axis coincides with a known one of the two extreme axes of the given body), and also the total angular velocity; the corresponding position of the node and value of the total angular velocity of the original body are then known by simple arithmetical computations from the theorems above given, involving λ only for the first, and λ, L, M for the second. 2nd. If the reduction is contrary or supplemental, we have only to substitute the supplemental angles of inclination to the invariable line in determining t_0, and proceed in all other respects as before, taking the supplements of

---

Hence

$$\frac{\mathrm{M}}{\mathrm{L}}dt=\frac{dz}{\sqrt{\mathrm{Z}_1\mathrm{Z}_2}},$$

where

$$\mathrm{Z}_1=\left(1-\frac{1}{q_2}\right)+z^2\left(\frac{1}{q_2}-\frac{1}{q_1+q_2}\right),$$

$$\mathrm{Z}_2=\left(1-\frac{1}{q_1}\right)+z^2\left(\frac{1}{q_1}-\frac{1}{q_1+q_2}\right),$$

and

$$d\zeta=\frac{1}{q_1+q_2}\,\frac{dz}{\sqrt{\mathrm{Z}_1\mathrm{Z}_2}}+\left(1-\frac{1}{q_1+q_2}\right)\frac{dz}{(1-z^2)\sqrt{\mathrm{Z}_1\mathrm{Z}_2}}.$$

The limiting values of z correspond to $\mathrm{Z}_1=0$, $\mathrm{Z}_2=0$, or, which is the same thing, to the values of z when y and x are successively made zero in the equation (1).

It may be useful to the reader to be enabled to compare the above values of t and ζ in terms of z with the equivalent determination of LEGENDRE, Exerc. du Cal. Intég. tome ii. p. 334,

$$\text{viz. } i\,dt=\frac{d\psi}{\sqrt{1-c^2(\sin\psi)^2}},$$

$$d\phi=\frac{2\tan\mu}{1-m\sin\beta}\cdot\left(\frac{n+1}{2}\,\frac{d\psi}{\sqrt{1-c^2(\sin\psi)^2}}-\frac{d\psi}{(1+(\tan\mu)^2(\sin\psi)^2)\sqrt{1-c^2(\sin\psi)^2}}\right);$$

for this purpose it will be necessary to bear in mind that LEGENDRE's A, B, C are not the moments of inertia themselves, but the elements out of whose binary combinations they are formed, and that his middle magnitude is not B but A; the reader will then find it necessary to trace the values of LEGENDRE's i, W, ε, ψ, θ, β, m, n, μ, c by the formulæ and definitions given at pages 334, 319, 328, 315, 321, 322, 325, 319 *bis*, 333, and possibly some other which has disappeared from my notes of the Exercises, tome ii.

the angles given in the tables in lieu of the angles themselves. In the special case of a body with two equal moments of inertia, were not the simplicity of the motion such as to render tabulation unnecessary, a distinct set of tables of double entry would of course be employed. It is, I think, conceivable that the supposed tables of treble entry might be of some practical value in studying by arithmetical or graphical methods the geological phenomenon of evagation of the pole of the earth regarded as a body of irregular form, and in other dynamical problems of a gyroscopical character where an exact determination of the effect of a given disturbing cause might be difficult or unattainable.

The fact that there are no essential differences in the motion of a rigid body of any form and started under any initial circumstances whatever, but such as depend upon the particular values of the two positive proper fractions q_1, q_2, enables us at once to see what are the special cases which alone can arise, and whether or no there is any real distinction to be made between the general cases of the theory. At first sight it would seem that four essential parameters enter into the question, the ratios of the initial values of the partial velocities ω_1, ω_2, ω_3, and the ratios of the constants A : B : C, the principal moments of inertia; but one parameter is saved by the substitution of an indefinitely flattened disk for a solid, and another by the introduction of an intrinsic epoch from which the time is reckoned, and thus a table of treble instead of quintuple entry is competent to represent every possible variety of conditions.

The problem that has been treated of in the foregoing pages is one (and possibly the simplest) instance of a well-defined class of dynamical questions subject to a peculiar method of treatment, which consists in the postponement of the determination of the absolute displacement of the moving system until after its displacement relative to a fixed line has been previously determined. The three problems which may be said to form a natural (not merely a historically connected) group, and which offer the most important illustrations of the class in question, are those of the rotation of a free body, of the motion of a particle attracted to two fixed centres of force, and the problem of three bodies. In the first and third of these, the invariable line is a line perpendicular to the invariable plane, determinable by composition of the momenta of the several elements of the system at any instant of time. In the second the invariable line is the line joining the fixed centres; and the distances of the moving point from the two fixed centres or the angles which they make with the line of centres may be expressed by equations complete within themselves, and into which the position of the plane containing the moveable point and the fixed line does not enter. So again in the problem of three bodies, without having recourse to the methods of deformation employed by JACOBI, and those who have followed in his track in treating the question, it is obvious, *à priori*, that one integral may be gained, in the sense of one less being required, by forming a system of equations from which the position of the intersection of the plane of the three bodies with the invariable plane is excluded, equivalent in effect to the so-called "elimination of the node" on JACOBI'S method; in which, however, the node so called is not to be confounded with the intersection above named, but is the mutual intersection of two ideal instantaneous orbits with each other and the invariable plane.

In every ordinary dynamical problem, by a well-known simple contrivance, the *time* element may be preliminarily thrown out of the differential equations of the motion; in the class of which the three noble and celebrated questions here referred to are the conspicuous types, a certain space element is capable of being similarly left out to the end; thus the number of linear differential equations required for the determination of the remaining elements is reduced by two, and if *all* the integrals of this reduced system are capable of being found, then we know, *à priori*, by the theory of the last multiplier, how to reduce to quadratures the values of the two outstanding elements. The process whereby the space coordinate referring to absolute position is, so to say, avoided in this class of dynamical questions, is not, or at least need not be considered as, one of elimination properly so called; elimination is the act of extruding a variable from a system of equations in which it has appeared; the process to be applied in the case before us is one not of extrusion, but of exclusion *ab initio*, or as it may be rendered in a single word, of ab-limination.

I propose at an early moment to return to a consideration of the particular method of ab-limination above indicated as applicable to the problem of three bodies, in the study of which this memoir took its rise.

XXVI. *The Calculus of Chemical Operations; being a Method for the Investigation, by means of Symbols, of the Laws of the Distribution of Weight in Chemical Change.* —Part I. *On the Construction of Chemical Symbols.* *By Sir* B. C. BRODIE, *Bart., F.R.S., Professor of Chemistry in the University of Oxford.*

Received April 25,—Read May 3, 1866.

"*Les formules chimiques, comme nous l'avons dit, ne sont pas destinées à représenter l'arrangement des atomes, mais elles ont pour but de rendre évidentes, de la manière la plus simple et la plus exacte, les relations qui rattachent les corps entre eux sous le rapport des transformations.*"—GERHARDT.

CONTENTS.

Introduction 781

Section I. DEFINITIONS.—(1) Term "ponderable matter."—(2) "A chemical substance."—(3) "A weight."—(4) "A single weight."—(5) "A group of weights."—(6) "Identical weights."—(7) "A compound weight."—(8) A "simple weight."—(9) An "integral compound weight."—(10) "Unit of ponderable matter."—(11) "Unit of space."—(12) Term "distribution of weight."—"A distributed weight."—"An undistributed weight." 789

Section II. ON THE SYMBOLS OF CHEMICAL OPERATIONS.—(1) Definition of "a chemical operation."—Symbols of chemical operations, x, x_1, x_2.—Term "chemical function."—(2) Symbol of identity, $=$.—(3) Symbols of the operations by which groups are constituted, $+$ and $-$.—Symbol 0 selected as the symbol of $x-x$.—(4) Symbol of two weights collectively considered, $(x+x_1)$.—(5) Symbols of compound weights, xy and $\frac{x}{y}$.—Commutative property of chemical symbols.—(6) Interpretation and properties of the symbol $x(y+y_1)$ 794

Section III. ON THE CHEMICAL SYMBOL 1.—(1) The symbol 1 selected as the symbol of the unit of space.—(2) Various forms of the symbol 1.—Symbols x^0 and $\frac{x}{x}$.—(3) Symbol ∞ 798

Section IV. ON THE FUNDAMENTAL CHEMICAL EQUATIONS.—(1) Equations $xy=x+y$ and $\frac{x}{y}=x-y$.—(2) Deduction of the forms of the symbol 1 from the fundamental equations.—(3) Consideration of the equation $0=n$.—(4) Logarithmic property of chemical symbols 801

Section V. ON THE SYMBOLS OF SIMPLE WEIGHTS.—(1) Term "prime factors."—(2, 3, 4, 5, 6, 7, 8) Properties of these symbols.—(9) Symbol of an integral compound weight.—(10) On the expression of chemical symbols by means of prime factors in a given system of equations 804

Section VI. ON THE CONSTRUCTION OF CHEMICAL EQUATIONS FROM THE DATA AFFORDED BY EXPERIMENT 808

Section VII. ON THE SYMBOLS OF THE UNITS OF CHEMICAL SUBSTANCES 810

Group 1, p. 810.—(1) Hydrogen.—Definition of the term "modulus."—(2) Oxygen.—(3) Sulphur.—(4) Selenium.—(5) Chlorine.—(6) Iodine.—(7) Bromine.—(8) Nitrogen.—(9) Phosphorus.—(10) Arsenic.—(11) Mercury.

Group 2, p. 827.—(1) Carbon.—(2) Silicon.—(3) Boron.

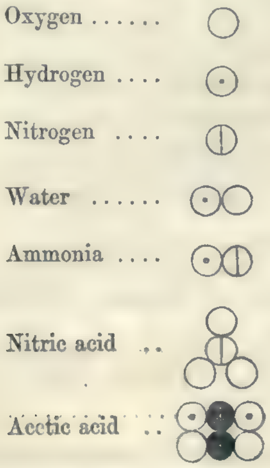
Group 3, p. 839.—(1) On the relation which exists between the vapour-density and the specific heat of the elemental bodies.—(2) Symbol of Antimony.—(3) Bismuth.—(4) Tin.—(5) Zinc.—(6) Cadmium.—(7) Silver.

Section VIII. ON THE APPARENT EXCEPTIONS TO THE LAW OF PRIME FACTORS.—(1) Chloride of ammonium.—(2) Binoxide of nitrogen.—(3) Table of exceptions 851

Conclusion 855

EVEN in the earliest times the attention of chemists seems to have been directed to the symbolic expression of the facts of their science, a method which had its origin in the mystic spirit of alchemy, and the subject has never ceased to occupy a prominent position in chemical philosophy. However, the development of our symbolic system has by no means kept pace with the general progress of the science. Indeed no essential improvement in the method has been effected since its first invention by BERZELIUS; and though this notation has doubtless afforded much aid to memory, and through memory incidentally to reasoning, yet it is difficult to point to even one discovery in the science, for which we are indebted to symbolic operations. In this respect chemical symbols present a marked contrast to other symbolic systems. The application of symbols to geometry and mechanics immediately led to the discovery of important truths, which were followed by the most original and unexpected development of the symbolic method itself. A very slight examination, however, of our present system is sufficient to render evident, that not only are the symbols of the chemist wanting in precision, but that they are of a totally different order from those symbols the employment of which has been attended with such great results.

The question of chemical symbols cannot well be separated from the consideration of the hypothesis which is expressed in them. The actual theory of chemistry is based upon the atomic theory of DALTON, and in the 'New System of Chemical Philosophy' may be found the germ whence our notation has been developed. According to the views of this eminent philosopher, the ponderable matter of any portion of the elemental bodies is assumed to consist of a vast yet finite number of minute, indivisible, and homogeneous particles or atoms, by the varied combinations of which all other substances may be produced. With the object of elucidating his theory, DALTON gave (in the plates at the end of his work) a kind of pictorial representation of the nature of matter from the point of view of his hypothesis. He represented the atoms of the elements by single circles with a characteristic mark, and the molecules of compound substances by systems of circles placed side by side in the figure, as the atoms were supposed to be placed in nature. Such pictures, for instance, are the following[*], by which he figured oxygen, hydrogen, nitrogen, water, ammonia, nitric and acetic acids.



---

[*] See 'New System of Chemical Philosophy,' part 1, p. 219.

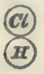
In our present system these signs have been replaced by letters marking the weights of the atoms, and the circles have been removed. But no fundamental change has been made in his conception, and in the arrangement of letters H_2, O_2, H_2O and the like, we still retain the image of DALTON under another form. Indeed where special clearness is required we not unfrequently find the circles restored to the picture; and the most recent representation of the nature of matter consists in a modification of this concrete symbol to meet the necessities of modern ideas[*]. On this view that arrangement of letters in the symbol which we call a formula is to be regarded as a figure by which the arrangement of atoms in the substance is represented; the symbolic system being a sort of orrery[†], in which is imperfectly imitated the structure and movements of that unseen molecular world, on the mechanism of which chemical transformations are assumed to depend. A still more exact comparison would perhaps be to a diagram of Euclid, which bears a certain, though a confessedly inexact, resemblance to the object signified, and serves by this likeness to bring it vividly before the imagination[‡].

This molecular interpretation is, it must be admitted, rather a matter of tacit convention than of express statement, and the above remarks, without qualification, would be too general. For it is a striking feature in our science that no system of chemical notation has yet been devised of such a nature as to receive universal and unqualified assent, or even a uniform interpretation. BERZELIUS[§], who is generally regarded as the originator of our present method, considered that the letters which he employed simply represented certain weights of matter, and that in the symbol of a chemical substance the sign + was

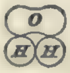
---

[*] See KEKULÉ, 'Lehrbuch der organischen Chemie,' 1861, p. 160, where the following diagrams are given:—

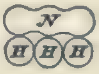
Hydrochloric acid ..



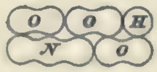
Water ....



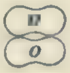
Ammonia ....



Nitric acid ....



Oxygen ....



[†] "But formulæ may be used in an entirely different and yet perfectly definite manner, and the use of the two distinct points of view will perhaps not be unserviceable. They may be used as an actual image of what we rationally suppose to be the arrangement of the constituent atoms in a compound, as an orrery is an image of what we conclude to be the arrangement of our planetary system."—"On the Constitution of Salts," by A. W. WILLIAMSON, Journal of the Chemical Society, vol. iv. p. 351.

[‡] An interesting account of the development of our present system of notation, and its relation to the atomic theory, is given in the article "Notation" in WATTS's Dictionary of Chemistry, by Professor G. C. FOSTER.

[§] BERZELIUS, 'Traité de Chimie,' 1845, vol. i. p. 119; and 'Jahresbericht,' vol. xv. p. 201.

to be understood as connecting every letter in the symbol, and was suppressed only from motives of brevity and convenience. So that H_2O was an abbreviated expression for $H+H+O$; H and O being numbers by which the relative weights of the combining proportions of hydrogen and oxygen were expressed. Sir JOHN HERSCHEL, in a paper contained in the Edinburgh Philosophical Journal for 1819*, and more recently in his introductory address to the Chemical Section of the British Association at Leeds, in the year 1858, objected to this system of chemical notation as opposed to algebraic convention, and suggested the replacement of the symbol H_2O, for example, by the expression $2H+\ddot{O}$, arguing that the apposition of letters, being the algebraic sign of multiplication, cannot, consistently with the conventional principles of algebra, be employed to express the sum of two weights. GERHARDT, while he admitted the general principles of the atomic mode of representation, ridiculed all attempts to express the grouping and arrangement of atoms. Such, indeed, is the prevailing uncertainty that even in express treatises on chemistry all details on the subject are frequently evaded, and symbols are introduced and employed without any precise meaning being assigned to them. Such latitude is obviously inconsistent with the methods of science, and it has been proposed by more than one chemist, to whose more exact turn of mind it was eminently distasteful, that we should return to the simpler system of BERZELIUS. We are not, however, justified in concluding, as some have done, that because these symbols are wanting in precision, therefore they are utterly without reason or utility, mere idle arrangements of letters to which no serious meaning can be attached†. On the contrary, a more candid appreciation cannot fail to recognize that, notwithstanding many imperfections, they have rendered a most important service, by affording an external and visible image of the world of chemistry on which the attention may advantageously be concentrated. Ordinary language is too vague and too diffuse for the purposes of science, and in chemistry especially the facts are so numerous and so complicated that it is only when embodied in a concrete form that they can be stored in the memory, and become the object of reflection. Hence even an imperfect and material picture may, in a certain epoch of the development of the science, be found of indispensable utility.

---

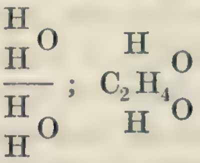
* See Edinburgh Philosophical Journal, vol. i. pp. 8, 18, 28.

† See BERTHELOT, 'Chimie organique, fondée sur la synthèse,' 1860, Introduction, p. cxxii, and p. 189. If the principles laid down by M. BERTHELOT are to be regarded as literally correct, the questions raised in the present memoir are unworthy of any serious consideration whatever.

"Ce serait méconnaître étrangement la philosophie des sciences naturelles et expérimentales, que d'attribuer à de semblables mécanismes une portée fondamentale. En effet, dans l'étude des sciences, tout réside dans la découverte des faits généraux, et dans celles des lois qui les rattachent les uns aux autres. Peu importe le langage par lequel on les exprime; c'est une affaire d'exposition, plutôt que d'invention véritable: les signes n'ont de valeur que par les faits dont ils sont l'image. Mais les conséquences logiques d'une idée ne changent point, quelle que soit la langue dans laquelle on la traduit."

It is a fundamental principle of symbolic reasoning, to whatever science it may be applied, that we cannot by the aid of symbols arrive at any conclusion which is not implicitly contained in them. And it might with equal justice be asserted that it was a matter of very little consequence whether we employed for the purposes of calculation Arabic or Roman numerals, the number expressed being in either case precisely the same, and "the language by which it is expressed being of little moment." Or again, that the discovery of the method of denoting the position of points in space by means of the symbols of algebraic geometry was a very unimportant matter. Our conception of a circle is the same as that of the ancient geometricians, and "the logical consequences of an idea do not change into whatever language we translate it." Nevertheless our power of following out and appreciating those consequences may be very materially affected by such a method, as experience has amply proved.

The actual theory of chemistry may be regarded as an expansion of the hypothesis of Dalton. In science, as in other spheres of thought, hypotheses often pass without question which come to us recommended by early use, and by even a short tradition; and when embodied in symbolic language, and thus intimately blended with our conceptions, they are readily mistaken for facts. No statement, perhaps, would receive more universal or unqualified assent from chemists than that the molecule of ammonia contains three atoms of hydrogen, that ethylamine is derived from ammonia by the substitution of an atom of ethyl for an atom of hydrogen, and that the reason why there are three, and only three, such derivatives of ammonia is, that each derivative is formed by a repetition of the same process, and that, the molecule of ammonia containing only three atoms of hydrogen, this process can only be repeated three times. These conclusions are regarded as so certain as to be almost removed from discussion. But nevertheless they cannot but partake of the hypothetical nature of the theory in which they originated. It is only because our primary hypothesis has led us to take this peculiar view of the atomic constitution of ammonia, and to express it by the symbol NH_3, that chemists have adopted these further hypotheses as to the nature of the process by which ethylamine is formed, and as to the cause of the limitation which exists in regard to the number of these derivatives. Again, the theory of atomicity has a similar origin. Glycol is supposed to be derived from two molecules of water by the substitution of an atom of the diatomic hydrocarbon ethylene for two atoms of hydrogen; the diatomic radical, in the forcible language of the distinguished discoverer of this substance, "welding" and "riveting" together the residues of the two molecules of water*. What is this doctrine? It is simply the expression in language of the relation of the symbols



$$\begin{array}{l} \begin{matrix}H\\H\end{matrix}O \\ \hline \begin{matrix}H\\H\end{matrix}O \end{array} ; \quad \begin{array}{l} H \\ C_2H_4 \\ H \end{array}\begin{matrix}O\\ \\O\end{matrix}$$

And if the course of the science had been, as might have been the case, such as to have led us to a different view of the atomic constitution of these substances, we should have a different order of chemical ideas, and the theory, in its actual form, would never have existed.

---

* "Toutes ces molécules sont cimentées, en quelque sorte, par des éléments polyatomiques, qui possèdent la propriété de se souder les uns aux autres."

"Il est bien entendu que dans l'éthyle lui-même les atomes sont rivés ensemble par le carbone tétratomique." —Wurtz, 'Leçons de Philosophie Chimique,' 1864, pp. 138–140.

It is frequently asserted that our present hypothesis affords a clear and simple explanation of chemical phenomena, which is the evidence of its truth. Now it may be considered that such an explanation was perhaps afforded of the incomplete system of facts known to DALTON, but with our present knowledge this account can no longer be regarded as satisfactory. The most important feature in our modern system is the identification of the weight of the chemical molecule with the weight of the unit of gaseous volume, to which we are brought by physical as well as chemical considerations. This great simplification was practically introduced by LAURENT and GERHARDT, and it is generally allowed that this assumption affords the surest basis of chemical theory. Now the atomic theory of DALTON accounts for the fact that the weight of the chemical molecule may be regarded as consisting of an integral number of the atomic weights of those elemental bodies into which it can finally be decomposed. But this is not the only limitation with which we are acquainted. The chemists before mentioned discovered the existence of a peculiar numerical relation between the atomic weights of certain elemental bodies, when combined in the chemical molecule, to which they gave the name of "the law of even numbers." This law may be thus stated:—"The sum of the volumes of the hydrogen, chlorine, bromine, iodine, nitrogen, and generally of that class of elements which goes under the name of the dyad elements, which are formed by the decomposition of two gaseous volumes of any chemical substance, is an even number"*. This statement rests upon evidence quite as satisfactory as that by which the atomic doctrine is supported. A formula containing an uneven number of these elements jointly is rendered as improbable, from our experience, as a formula containing fractions of atoms. But the atomic theory in its present form takes no account of this relation, and so little has this great discovery been appreciated that such formulæ are often met with, even in the works of accomplished chemists; and indeed they are truly admissible, so far as the limitations imposed by our actual theory are concerned. It need not certainly be a matter for surprise or reproach, that the speculations of DALTON should not apply to a class of facts with which he was unacquainted; nor even can this be regarded as conclusive evidence against the truth of his system. But nevertheless this omission indicates some profound defect in chemical theory, and if it should be found that another view of the constitution of matter should cover the whole ground, and account by one and the same hypothesis for both numerical relations, there can be but little room for doubt as to which should be preferred.

Another, although a less important, defect in our method is the singular unit of volume which chemists have been compelled to adopt, for which selection no reason can be assigned except the necessities of the atomic hypothesis. In the so-called "two-volume" and "four-volume" notations the weight of the chemical unit or molecule is assumed as twice or four times the weight of the unit adopted for the purposes of physical measurement, the numbers which express the weight of the chemical molecule being proportional to, but not identical with, the numbers which express its density. An attempt has been made to remedy this imperfection, retaining the general features of our present method, but the changes proposed have never been adopted, such alterations being always attended with some inconvenience, and the question at issue being one neither of theory nor of fact*.

---

* See LAURENT, Méthode de Chimie, Ed. 1854, p. 57, "Sur les nombres pairs d'atomes;" 'Chemical Method,' English translation, 1855, p. 46.

The following pages contain the outline of a new method for the expression, by means of symbols, of the exact facts of chemistry, and for reasoning upon these facts by their aid. This method is quite independent of any atomic hypothesis as to the nature of the material world, and in it the symbol is placed in immediate relation with the fact, being indeed its symbolic equivalent or expression. It does not, however, preclude or deny such an hypothesis; the question is not raised. This method may be regarded as a special application of the science of algebra, and in its construction I have been guided by the similar applications of that science to geometry, to probabilities, and to logic, to which it presents many curious and interesting analogies. In these branches of science the symbol is not a figure of the object, nor is any resemblance attempted between the symbol and the thing signified by it. The symbols which I shall have occasion to employ are of the same abstract character; they pretend to no resemblance to any object in nature, and are simply to be regarded as arrangements of marks which it is convenient to employ for the purposes of thought. The conditions to be satisfied by such a method are few and simple. It is only necessary that every symbol should be accurately defined; that every arrangement of symbols should be limited by fixed rules of construction, the propriety of which can be demonstrated; and that the symbolic processes employed should lead to results which admit of interpretation.

The object of this method may be considered to be the investigation of the laws of the distribution of weight in chemical changes, and the symbols here employed represent "weights" in the same sense as the symbols of geometry represent lines or surfaces. Now the symbol a in geometry, in its primary sense, may be regarded as the symbol of the operation performed upon the unit of length, by which a line is generated, that is, of which the result is a line. In like manner the symbol a, as a chemical symbol, is to be regarded as the symbol of the operation performed upon a unit of space, by which a weight is generated, that is, of which the result is a weight. Symbols of operation have not hitherto been adopted in chemistry, and their introduction forms a distinctive feature of the present method, which I have hence termed "the Calculus of Chemical Operations."

It is my intention to divide the subject into three parts. The first part, which alone is here given, relates to the construction of chemical symbols. In the second part I purpose to treat of the theory of chemical equations, which is intimately connected with the general processes of chemical reasoning, and especially with the consideration of the nature of that event which is termed a chemical change, of which I shall give a new analysis founded on its symbolic expression. In the third part it is intended to consider the principles of symbolic classification and the light thrown by this method upon the origin and nature of the numerical laws which limit the distribution of weight in chemical change: I shall then have occasion to contrast the view of the science which is here given with that afforded by our existing system.

---

* See LAURENT, 'Méthode de Chimie,' p. 83, English translation, p. 67. Also Mr. J. J. WATERSTON "On Chemical Notation in conformity with the Dynamical Theory of Heat," Phil. Mag. vol. xxvi. pp. 248 and 515, and vol. xxvii. p. 273. Also "Remarks on Chemical Notation," by W. ODLING, *Ib.* vol. xxvi. p. 380, and vol. xxvii. p. 380. The proposition of Mr. WATERSTON is the same as that of LAURENT, and amounts to the obvious expedient of cutting the molecules and atoms in half.

It is now some years since the conception of such a work first arose in my mind, and these pages are a very imperfect record of the time and consideration bestowed upon it, which yet can hardly be regarded as excessive in relation to the end I have had in view, which has been no other than to free the science of chemistry from the trammels imposed upon it by accumulated hypotheses, and to endow it with the most necessary of all the instruments of progressive thought, an exact and rational language. "Tout langue est une méthode analytique, et toute méthode analytique est une langue."—CONDILLAC. The views here advocated may appear novel, but nevertheless I strongly feel that one claim, at least, which they have on the consideration of chemists is that they are in truth the rational and simple consequence of opinions at which the most reflecting minds have already arrived, and offer a more complete expression of current ideas than has hitherto been given. Indeed on such subjects novelty is almost inconsistent with truth. For the conceptions through which sciences pass necessarily have their origin in the views which preceded them, of which they are but the natural fruit. The method here developed will be seen, if carefully considered, to be but another step in the direction of the chemical movement of the last twenty years, which some imagine to have found its final consummation in the doctrines of "modern chemistry." Such could never have been the conclusion of the great chemists from whom this impulse emanated, who definitely refused to recognize the atomic doctrine as the adequate exponent of their ideas, and who implanted in the science the germ of a more abstract philosophy, which it has ever since retained.

The object of the following method has been defined as the investigation by means of symbols of the laws of the distribution of weight in chemical change, a problem evidently of the widest range, and embracing many distinct questions. To the consideration of one, and certainly not the least important, of these the first part of this work will be more especially devoted, namely, to the discovery of a system of symbolic expressions by which the composition of the units of weight of chemical substances may be accurately represented, and which may hereafter be employed for the purposes of chemical reasoning. The value of our conclusions must depend upon the degree of precision and certainty with which this point is determined. It will be shown that the problem is of a perfectly real nature, admitting, where the experimental data are adequately supplied, of only one solution. The discussion of this question involves the consideration of the fundamental principles of symbolic expression in chemistry.

SECTION I.—DEFINITIONS.

It is essential for the purposes of exact reasoning that the terms employed should be accurately defined. This can only be effected either by the invention of new words or by the selection from the many shades of meaning which may be attached to existing words of some one definite and appropriate signification, in which it shall be agreed to employ them. I shall adopt the latter and more obvious course.

1. The term "ponderable matter," in its chemical application, is a term by which that class of objects is denoted, the transformations of which form the special study of the chemist. Not that the property of weight can exist apart from those other properties of form, colour, and the like, with which, so far as our experience extends, it is invariably associated, but that in the actual phase of the science this property is chiefly considered, it being the only property of matter in regard to the chemical changes of which we possess any exact knowledge. No further explanation of this term can advantageously be offered, except by exhibiting or enumerating the objects (such as water, silica, oxygen) which are comprehended in the class.

2. A "chemical substance" is a portion of ponderable matter of which every part has the same properties.

It is often difficult to decide whether this condition be satisfied or not, but the propriety of the above definition will be manifest from the line of argument which is applicable to such cases. Take, for example, the case of atmospheric air. To a superficial observation, every part, however minute, of any given portion of the atmosphere has the same properties. But a more exact scrutiny leads us to infer that this is really not the case, but that it consists of parts, which diffuse with different velocities and are unequally soluble in water. On these principles it has been established that the gas procured from the decomposition of acetic acid is truly, in the sense of the above definition, one chemical substance, marsh-gas, and not two chemical substances, hydrogen and methyl.

3. "A weight" is a portion of ponderable matter of any specified kind considered as regards weight.

This application of the term *a weight* is only a slight extension of its ordinary use. A gramme of platinum which serves for the purposes of weighing is termed *a weight*, this being the only property of that portion of matter of which it is necessary to take cognizance*. Now the weight of matter, from a different and far wider point of view, in the laws of its composition and resolution, is the special subject of this investigation;

---

* The term weight is, in ordinary language, used with two distinct meanings. (1) In what may be termed its abstract signification, as denoting a certain measurable property of matter, as when we inquire, "What is the weight of that loaf?" (2) In its concrete sense, as denoting certain objects, which we discriminate from others by naming them from their most essential property, as when we say "Bring me that box of weights." It is in an extension of this concrete meaning that the word is here employed. It is not, of course, intended to assert that the transformation of *weights* is the only subject of chemical science, but simply to fix the attention upon that subject as the only topic which is here discussed.

and the aspect in which every chemical substance, every portion of ponderable matter, will be here regarded is exclusively as *a weight*. In speaking of such *weights* we habitually employ, by a tacit convention, the terms by which the chemical substances, of which the weight alone is referred to, are usually designated. But this is not a strictly accurate use of language; and it is necessary to observe that in the following pages, where chemical substances, such as chlorine or alcohol or water, are mentioned, or the term "a portion of matter" is employed, the objects referred to are certain weights of the substances under consideration, to the exclusion of all other properties.

4. "A single weight" is a portion of ponderable matter of any specified kind considered as regards weight and as one object, as for example a portion of oxygen, or a portion of ponderable matter consisting of oxygen and hydrochloric acid considered as one object, or two portions of oxygen similarly considered.

5. A "group of weights" is some number of single weights, such as a portion of oxygen and a portion of hydrochloric acid considered as two objects, or two portions of oxygen similarly considered. The single weights of which a group consists are termed the "constituents" of the group, which is said to be "constituted" of them.

6. Two portions of ponderable matter which consist of the same "weights" are said to be identical as regards weight.

It follows from this definition that what may be termed the absolute weight, or weight in grammes, of "identical weights" is equal.

Our knowledge as to the identical relations of ponderable matter is derived exclusively from the science of chemistry. Were we unacquainted with the peculiar phenomena of chemical transmutation, or were we ignorant of the circumstance that in chemical change the total weight of matter is unaltered, the existence of such relations would be unknown to us. It is so important to have a clear perception of that distinction, which is here made I believe for the first time, between equality and identity of weight, that a few words in somewhat fuller explanation of the grounds on which this distinction rests may not be deemed out of place.

If we were to take any portion, say a gramme, of water, and observe its properties on two successive days, the conditions under which the water was placed being assumed as fixed, it would be found that the properties of the water were precisely the same at the second as at the first observation. In this case the identity of properties would be absolute, and as we know that at whatever time the observation had been made, under the same conditions, the same result would have been obtained, we should hence arrive at the conception of the continuous existence of one and the same object, which we should denote with perfect precision by one and the same name, a gramme of water. Now let it be assumed that some condition varies, that the temperature, for example, rises from 60° to 90°, and let another observation be made of the properties of the water. It would be found that these properties were no longer identical with those previously observed; that the bulk of the water had increased, and that some properties had varied while others had remained constant. If the expansion of water were the point under consideration, those properties which had varied would be of fundamental importance; but as for most purposes these variations may be disregarded the object is still assumed to be the same, and called by the same name, a gramme of water. Let the temperature rise to 100°, and let a new observation be made. The liquid has become a gas, and the change of properties is so great that a new name is assigned to the portion of matter, and it is said that the gramme of water has been converted into a gramme of steam. Nevertheless, many of the properties of the steam are identical with those of the water, and these being the properties with which the chemist is mainly concerned, he asserts the identity of the two objects for the purposes of his science, and says, notwithstanding this transformation, that steam is simply the gaseous form of water. Now let the conditions be again varied. At a further elevation of temperature it will be found that a more profound change has occurred. In the place of one continuous portion of matter, in every part of which the same properties may be recognized, we have two distinct chemical substances, each characterized by a special set of properties. The volume has permanently altered; many chemical as well as physical properties of the water have entirely disappeared. The chemist marks this change by assigning a new name to the portion of matter, and says that the water has been *converted* into oxygen and hydrogen. It has, however, been found that even in this profound change one property has not been affected, namely, weight. This property is constant; and we assert in the most absolute sense that the weight of a gramme of water is identical with the weight of the gramme of oxygen and hydrogen into which it is transformed, for this property, throughout this series of changes, has never varied nor ceased to have a continuous existence. Now a gramme of water will produce the same effect on a balance as a gramme of lead, and it is this relation which is here termed equality of weight. This relation also subsists between the weight of a gramme of water and the weight of the gramme of oxygen and hydrogen into which it is transformed; but these weights are also connected by another relation, which I have termed identity, which does not exist between the gramme of water and the gramme of lead.

It is thus that we are led by experience to the inference comprised in the following statement.

If a portion of matter A be chemically converted into a portion of matter A_1, then the weights (or portions of matter considered as regards weight) of which A consists are identical with the weights (or portions of matter considered as regards weight) of which A_1 consists.

It will be found, on analyzing the process of reasoning by which we conclude the continuous existence of the same weight in a chemical change, that the evidence by which it is supported is precisely of the same order as that by which we are enabled to assert the continuous existence of any external object whatever. This evidence is brought spontaneously and without effort before the mind, and is so perfectly conclusive, however difficult it may be to submit it to analysis, that an eminent writer has actually imagined the doctrine of the permanence of weight in chemical changes to be a truth which the mind recognizes at once when stated, by some special intuition, as "flowing from the idea of substance"*. As to the nature of this process we are left in the dark. However, such assumptions are happily as unnecessary as they are unmeaning, and it is sufficient for all the objects of science if we admit this axiom to be the undoubted acquisition of those combined processes of reasoning and observation which are the only sources of exact knowledge.

7. A "compound weight" is a single weight of which the whole is identical with two or more weights. Such weights are termed the components of the compound weight, which is said to be composed of them.

It follows from this definition that every part, individually or separately considered, of a compound weight is proportionally identical with the same weights of which the totality is composed; that is to say, if the whole of a compound weight be identical with the weights A and B, $\frac{1}{n}$th part of that compound weight, in whatever way the division into parts be effected, is identical with $\frac{1}{n}$th part of the weight A and $\frac{1}{n}$th part of the weight B, and is similarly composed of those parts; and also it is to be inferred that if every $\frac{1}{n}$th part of a single weight be identical with $\frac{1}{n}$th part of a weight A and $\frac{1}{n}$th part of a weight B, the whole of that single weight is composed of the weights A and B.

A group of two or more weights may, in the sense of this definition, be regarded as a compound weight, if only every constituent of the group have a common component. Thus, for example, a group consisting of two portions of matter, of which the one is composed of A and B, and the other of A and C, may be regarded as a single weight (Sec. I. Def. 4) of which the totality is composed of A and $\overline{\text{B or C}}$; for if, regarding the group as one object, we agree not to effect the separation of its constituents, every $\frac{1}{n}$th part of that weight satisfies proportionally the same condition.

Some difficulty may perhaps be felt in assenting to the above reasoning, from a certain ambiguity in language in the use of the conjunctions "and" and "or." That these conjunctions have the same meaning, so far as the purposes of enumeration are concerned, is apparent on enumerating the constituents of a group with each conjunction. The language of symbols is free from this ambiguity, the two conjunctions being represented by one mark, as will hereafter be explained.

8. A "simple weight" is a weight which is not compound. It may also be defined as a weight which has only one component. Two weights are said to be simple in regard to one another which have no common component.

9. An "integral compound weight" is a weight which is composed of an integral number of simple weights.

---

* See WHEWELL's 'Philosophy of the Inductive Sciences,' vol. i. chap. iv. p. 412, ed. 1847, "On the Application of the Idea of Substance in Chemistry."

10. It is necessary to select a "unit of ponderable matter" which may serve as the common measure of those chemical properties which it is our desire to investigate. Such a standard, for example, would be supplied to us were we to select as the common term of comparison that portion of ponderable matter of which the absolute weight is one gramme. This plan would have the great advantage of proceeding upon accurate and certain data, but, on the other hand, the conclusions to which it leads would be of comparatively little interest. The present method aims at effecting a comparison of the chemical properties of those portions of ponderable matter which, in the condition of perfect gases, and compared at the same temperature and pressure, occupy equal volumes.

In the numbers which express the specific gravity of gases a similar comparison is made of the absolute and relative weights of the same portions of matter; and it will be found convenient to refer physical and chemical properties to the same standard. I shall therefore define the "chemical unit of ponderable matter" as that portion of ponderable matter which occupies the volume of 1000 cub. centims. at 0° C. and a pressure of 760 millims. of mercury. The weights of the chemical unit of ponderable matter may be expressed in two ways according to the object in view; as the absolute weight in grammes, and as the relative weight in reference to the weight of some one unit assumed as the standard of comparison. For this purpose the weight of the unit of hydrogen will be selected.

11. The volume of 1000 cub. centims. is here termed "the unit of space."

The system of chemical measurement which has grown up around the atomic theory is of a singular and artificial character. The chemist is accustomed to assume as his standard of comparison, not some real and existing object, but a "molecule," an imaginary arrangement of imaginary atoms, of which no precise definition, by which it can be recognized, has ever been given. It should at least be shown that a system thus constructed offers special facilities for thought. But in truth it has been found so perplexing in practice, that the most skilled teachers* have been forced to admit that the student requires to be initiated into this world of hypothesis by means of more concrete and exact ideas.

12. The term "distribution of weight" may be defined as that operation by which a compound weight is resolved into its component weights, or by which it is made up from those weights, regard being had to some special system of such events which is the subject of consideration.

---

* Two eminent chemists have recently given independent testimony to the value of a more real standard than is afforded by this imaginary "molecule." Dr. HOFMANN, in his 'Modern Chemistry,' has adopted the term "crith" to denote such a real unit,—a crith being the weight of 1000 cub. centims. of hydrogen at standard temperature and pressure. Professor WILLIAMSON has, from similar motives of utility, adopted an "absolute volume" of 11·2 litres, which is the bulk of a gramme of hydrogen, also at standard temperature and pressure. I now propose to advance another step in the same direction, and to substitute the real for the fictitious unit, not for a special object alone, or to pave the way for more important theories, but for all the purposes of chemistry.

See 'Modern Chemistry,' by A. W. HOFMANN, 1865, pp. 121 and 130; and 'Chemistry for Students,' by A. W. WILLIAMSON, p. 4.

A "distributed weight" is a weight which, in such a system of events, is resolved into two or more weights or made up from such weights.

An "undistributed weight" is a weight which, in the same system of events, is not so resolved or so made up. An undistributed weight may also be defined as a weight which is resolved into one weight, or made up from one weight alone.

This division of weights into distributed and undistributed weights is coextensive with the previous division of the same into compound and simple weights. A distributed weight is necessarily a compound weight, for we can always assert its identity as a whole with the parts into which it is distributed; and a weight which is not distributed can only be regarded as a simple weight, for, by hypothesis, no information is supplied to us from the system of events under consideration, which enables us to assert its identity with any other weights, such an assertion in every case being purely relative to the facts before us, and open to modification by the acquisition of further knowledge.

It is essential to remark that the previous definitions are definitions of abstract conceptions, which have immediate reference to the symbolic method developed in the following section, for the construction of which they afford an adequate basis, and which is necessarily more comprehensive than those special subjects of physical investigation to which it is hereafter to be applied.

SECTION II.—ON THE SYMBOLS OF CHEMICAL OPERATIONS.

Having explained the nature of those objects and relations which fall under the consideration of the chemist as the investigator of the laws of the distribution of weight, I proceed to consider their symbolic expression.

(1) Let a chemical operation be defined as an operation performed upon the unit of space, of which the result is "*a weight*" (Sec. I. Def. 3), and let x, x_1, x_2 be the symbols of such operations, of which the weights A, A_1, A_2 are the results. Then the symbols of operation, x, x_1, x_2, are termed (for brevity and convenience) the symbols of the weights A, A_1, A_2.

Any symbolic expression into which the symbols of chemical operation enter is termed a chemical function.

(2) Two chemical operations are said to be identical of which the results are identical as regards weight (Sec. I. Def. 6). Now let the symbol $=$ be the symbol of identity. Hence if the weight A be identical with the weight A_1, $x=x_1$.

(3) Further, let the symbol $+$ be the symbol of that operation by which a weight is added to a weight so as to constitute with it one group (Sec. I. Def. 5); and let the symbol $-$ be the symbol of that operation by which a weight is removed from a group of weights. These operations are expressed in language by the words "and" and "without."

From these definitions $x+x_1$ is to be regarded as the symbol of a group constituted of the two weights A and A_1, and $x+x$, that is, $2x$, is the symbol of two weights A, and $x-x_1$ is to be regarded as the symbol of the weight A without the weight A_1. For this latter operation to be performed it is necessary that the weight A_1 should be part of the weight A.

Now since a group which is constituted of the weights A and A_1 is identical with (Sec. I. Def. 6) a group which is constituted of A_1 and A, $x+x_1=x_1+x$.

Also, since it is immaterial in what order the operation is performed which results in the exclusion of a weight from a group $x-x_1=-x_1+x$.

If, in the expression $x-x_1$, $x_1=x$ the expression becomes the symbol of a group in which no weight appears; for it is the symbol of that weight which is the result of removing the weight A from the weight A, in other words, $x-x$ is the symbol of the weight A without the weight A, but the result of the successive performance of these operations is *no* ponderable matter. By analogy of interpretation to that of the symbol 0, regarded as a numerical symbol, let 0 be the symbol of a group in which no weight appears, and which has had its origin in the several performance of the operations x and $-x$; so that $x-x=0$.

The chemical symbol 0 has the property of the numerical symbol 0 given in the identity $0+x=x$; for the ponderable matter which results from adding the weight A to a group in which no weight appears is identical with the ponderable matter A.

Also, since a group is not affected by removing from it no weight, the symbol of a group is not affected by removing from it the symbol of no weight, and $0+x=+x=x$.

The interpretation which is here assigned to the symbols + and − is strictly analogous to that which has been given to them in the arithmetical and logical systems*. They are the symbols of those operations by which we form a group from its constituents, or remove the constituents from a group. These operations, which may be termed the operations of "aggregation" and "segregation," are found in every department of thought. No uniform meaning has hitherto been attached to the symbols + and − in chemistry, notwithstanding their constant use. The prevalent opinion seems to be in favour of the use of the symbol + as the symbol of "mechanical mixture"†. It is difficult to say what may be the exact signification of this term. In the present method, at any rate, no such interpretation is to be attached to the symbol, it being quite immaterial for the end in view whether the objects referred to be what is termed "mixed" or not. A similar uncertainty prevails in the use of the symbol of identity‡. The symbol = is sometimes employed in chemistry as the symbol of numerical equality, at other times as the symbol of chemical transmutation. So far as I am aware it has never yet been employed with the signification which I have assigned to it, nor has the relation which it here expresses been recognized in the conceptions of the science, among which it occupies so fundamental a position.

---

* Boole, 'Laws of Thought,' p. 32.

† See Odling's 'Manual of Chemistry,' vol. i. p. 4. "The sign + signifies addition to, or rather mixture with." Also, Williamson's 'Chemistry for Students,' p. 37. "The sign + interposed between symbols denotes addition or mixture of the atoms or molecules which the symbols represent. Thus H+O denotes a mixture of 1 part by weight of hydrogen with 16 parts by weight of oxygen."

‡ Odling's 'Chemistry,' vol. i. p. 4. "The sign = signifies equivalency with, or rather conversion into." Williamson says, p. 37, "The sign = is used in describing chemical changes. It only denotes equality in weight between the sum of the atoms of each kind on one side of it, and the sum of the atoms of the same kind on the other side of it....... $H^2+O=H^2O$ means that 2 parts by weight of hydrogen added to 16 parts by weight of oxygen, can be made to combine to form 18 parts by weight of water."

(4) Further, let $\overline{x+x_1}$ or $(x+x_1)$ be the symbol of the two weights A and A_1 collectively considered as constituting a single weight. Then $\overline{x+x_1}+\overline{y+y_1}$ will be the symbol of a group of which two such weights are the constituents, and $\overline{(x+x_1)+(y+y_1)}$ will be the symbol of two such weights collectively considered, and as constituting a single weight.

Now, since the result is the same whether we add or remove a group of weights collectively, or add or remove the constituents of the group severally,

$$x+\overline{y+y_1}=x+y+y_1,$$
$$x-\overline{y+y_1}=x-y-y_1,$$
$$x+\overline{y-y_1}=x+y-y_1,$$
$$x-\overline{y-y_1}=x-y+y_1.$$

From this we may infer that the chemical symbols + and − have the properties of the numerical symbols + and −, so that

$$++x=+x,$$
$$-+x=-x,$$
$$+-x=-x,$$
$$--x=+x.$$

(5) Now, let W be a compound weight, of which certain portions of matter named A and B are the components (Sec. I. Def. 7). Let φ be the symbol of the weight W, and x and y the symbols of the weights A and B respectively. Further, let xy be selected as the symbol of the weight W, so that

$$\varphi=xy;$$

xy is termed a composite symbol, of which x and y are the factors. The symbol xy is also termed a combination of x and y, which are said to be combined in it.

If $y=x$, then $\varphi=xx$, which may also be written x^2; and generally if φ be the symbol of a compound weight of which the component weights are n weights named A, n_1 weights named A_1, n_2 weights named A_2 . . . . ., of which x, x_1, x_2, ... are the symbols, then

$$\varphi=x^n x_1^{n_1} x_2^{n_2} \ldots\ldots$$

If in this expression $x=x_1=x_2 \ldots\ldots$,

$$\varphi=x^{n+n_1+n_2+\ldots\ldots}.$$

Now, recurring to the symbol xy, since a portion of ponderable matter composed of A and B is identical with a portion of ponderable matter composed of B and A,

$$xy=yx,$$

that is to say, the order in which apposed symbols of chemical operations are written is indifferent. Symbols possessing this property are termed "commutative".

A consequence of this commutative property is that

$$(xy)^n = x^n y^n;$$

for

$$(xy)^2 = xyxy$$
$$= xxyy$$
$$= x^2y^2.$$

Further, let there be a compound weight V, of which θ is the symbol, of such a nature that it is identical with the component weight A without the component weight B, and let $\frac{x}{y}$ be selected as the symbol of the weight V. Then

$$\theta = \frac{x}{y},$$

whence, on similar principles, if θ be the symbol of a compound weight V identical with n component weights A, n_1 component weights A_1, n_2 component weights A_2, ... without m component weights B, m_1 component weights B_1, m_2 component weights B_2....,

$$\theta = \frac{x^n x_1^{n_1} x_2^{n_2} \dots.}{y^m y_1^{m_1} y_2^{m_2} \dots},$$

where $x, x_1, x_2, \dots. \; y, y_1, y_2, \dots.$ are the symbols of the weights A, A_1, A_2, ..., B, B_1, B_2.... respectively.

We may also reason thus: xy is the symbol of a weight which results from the successive performance upon the unit of space of the operations y and x, yx is the symbol of a weight which results from the performance of these operations in an inverted order, and (xy) is the symbol of a weight which results from their joint performance. Now, since the result is the same in whatever order the operations be performed, and since it is immaterial whether the operations be performed jointly or successively, we infer that

$$xy = yx = (xy).$$

(6) If in the composite symbol ϕ one of the factors be the symbol of a group, so that

$$\phi = x(y + y_1),$$

ϕ is to be interpreted as the symbol of the weight which results from the combination of the weight A with the group of weights B and B_1, the group being collectively considered and as constituting a single weight (Sec. I. Def. 4, 5, and Sec. II. (4)),—not, however, be it observed, a single weight *compounded* of the weights B and B_1, which would be symbolized by yy_1, but a single weight *constituted* of B and B_1 which is symbolized by $(y + y_1)$. (Sec. I. Def. 4, 5, and 7). Now the weight A will be combined with the group of weights *collectively* considered, if it be combined with the constituents of the group *severally*, but the symbol of the weight A combined with the two constituents of the group severally is $xy + xy_1$. We hence arrive at two symbols for the same weight, which express indeed two different aspects of the same object, but which are identical as regards the object signified; whence

$$x(y + y_1) = xy + xy_1.$$

Also by a strictly analogous interpretation to that assigned to the symbol xy as a symbol of operation, the symbol $x(y+y_1)$ is to be interpreted as the symbol of a weight which results from the successive performance upon the unit of space of the single operations $(y+y_1)$ and x. Now the result of performing the *single* operation $(y+y_1)$ is the same as that of performing *severally* the two operations y and y_1; and as regards the result, it is immaterial whether we first perform *severally* the two operations $y+y_1$, and then perform upon these *two* operations the operation indicated by x, as expressed in the symbol $xy+xy_1$, or whether we perform the *single* operation $(y+y_1)$ and then perform x upon that, as expressed in the symbol $x(y+y_1)$. From whichever point of view we regard the symbols, whether as symbols of operation or as symbols of the results of operations, we are brought to the same conclusion, that

$$x(y+y_1)=xy+xy_1.$$

In like manner it may be shown that

$$(x+x_1)(y+y_1)=xy+xy_1+x_1y+x_1y_1,$$

$(x+x_1)(y+y_1)$ being the symbol of a single compound weight, of which the groups A or A_1 and B or B_1 are the components. Symbols which possess this property are termed distributive symbols.

(7) Although the selection of a symbol is in a certain sense arbitrary, it is by no means a matter of indifference; and the symbol xy which is here assigned to a continuous compound weight, so far from being (as might be thought from a superficial consideration) contrary to symbolic analogy, is the only symbol by which the desired end could be attained, consistently with usage. The symbol xy in its abstract interpretation is the symbol of the operations x and y operating *successively* upon the unit or subject of operations; (xy) is the symbol of the same operations but operating *jointly*; $x+y$ is the symbol of the same operations operating upon the same subject but operating *severally*, and $(x+y)$ the symbol of the same operations but operating *collectively*. This fundamental distinction in operations as *successively*, *jointly*, *severally*, or *collectively* performed, appears in various forms in the different sciences, and is found in every branch of knowledge which admits of symbolic treatment. In chemistry it expresses the various ways in which we may conceive of the existence of the same ponderable matter. The language of symbols supplies the means of simply and adequately expressing these conceptions, isolated from every other consideration, which are not only very imperfectly expressed by the usual molecular representation, but are there complicated by many considerations which are totally irrelevant to the real point at issue.

SECTION III.—ON THE CHEMICAL SYMBOL 1.

(1) The preceding considerations suggest the inquiry as to the symbol of a compound weight of which the weight A and no weight are the components. Now, since any portion of ponderable matter is not altered by the combination with it of no ponderable

matter, a weight of which the weight A and no weight are the components is the same as the weight A. Hence if x be the symbol of the weight A, and y the symbol of no weight,

$$xy=x.$$

Now the symbol 1 regarded as a numerical symbol, possesses the property given in the equation

$$x1=x.$$

From this correspondence of symbolic properties, and guided by the same considerations of analogy as those on which the symbol 0 was selected as the symbol of no weight, regarded as the constituent of a group, I shall select the symbol 1 as the chemical symbol of no weight regarded as a component of a compound weight.

Since any portion of matter whatever may be considered as a compound weight of which that matter itself and no weight are the components, if ϕ be the symbol of any weight,

$$\phi=\phi 1.$$

The symbol 1, therefore, is implicitly contained as a common factor in every chemical symbol, being either expressed or understood as the symbol of the common subject of all chemical operations. Now this subject of chemical operations has been defined as the "unit of space" (Sec. I. Def. 11), a term already appropriated to it in language, for it is in space that we conceive of the existence of ponderable matter. This interpretation of the symbol 1, as the symbol of the unit of space, is identical with the meaning before assigned to it as the symbol of "no weight;" the only property of matter under consideration being weight, by the absence of which the unit of space is defined.

(2) The correctness of the above reasoning is further evident from the identity of the other algebraic forms of the chemical symbol 1 with the algebraic forms of the same numerical symbol, notwithstanding the difference in interpretation.

We have seen that x^n is the symbol of a compound weight, of which n weights A are the components. Hence the symbol of a compound weight, of which 0 (or no) weights A are the components, is x^0. But a weight of this kind is the same as "no weight;" whence

$$x^0=1.$$

The symbols 1 and x^0 correspond to the different ways in which "no weight" may have originated, the result being the same whether the operation performed do not cause weight or whether an operation causing weight be not performed; the former view being expressed by the symbol 1, the latter by x^0.

Again, if in the expression $\frac{x}{y}$ (Sec. II. (5)), $y=x$, this expression becomes the symbol of a compound weight composed of the weight A without the weight A, that is to say, which is composed of no weight; whence also

$$\frac{x}{x}=1.$$

This third form of the symbol 1 corresponds to a third origin of the absence of weight, which we may also regard as effected by the simultaneous performance of inverse operations upon the unit of space, the result of one of which is to cause "a weight," and of the other to remove the same. A correct system will take cognizance, not of one only, but of every way in which a given result can be attained.

There is considerable difficulty in the use of language for the expression of such abstract ideas, and these points would hardly become clearer by fuller explanation. Let it be sufficient, in conclusion, to state that the chemical symbol 1, while it is a necessary constituent of the system of chemical symbols, and may be and indeed must be employed to give effect to the purposes of the chemical calculus, is not to be interpreted in weight.

(3) An inquiry not without theoretical interest is immediately suggested by the previous considerations. We have arrived at the symbol of no ponderable matter, regarded as a component of a compound weight; what is the symbol of all ponderable matter, similarly regarded? Now all ponderable matter is characterized by the property that the addition to it of any finite weight does not alter our conception of it. Hence a compound weight, of which all ponderable matter and a finite weight are the components, is the same as a compound weight of which all ponderable matter is the single component. Hence, if y be the symbol of all ponderable matter thus regarded,

$$yx=y.$$

Now the numerical symbols 0 and ∞ satisfy this condition, since $0x=0$, and $\infty\, x=\infty$; and either symbol, so far as this equation is concerned, may be with equal propriety selected as the symbol of all ponderable matter. This is by no means contrary to analogy. As the numerical symbols 0 and ∞ are symbols of which all numbers are factors, so the chemical symbols 0 and ∞ are symbols of which all other chemical symbols are components,

$$\infty = x\,x_1\,x_2 \ldots\ldots \infty,$$

$$0 = x\,x_1\,x_2 \ldots\ldots 0.$$

In the same sense as the symbol 1 is to be interpreted as the symbol of space, so it will appear, on consideration, that the symbol ∞ is to be interpreted as the symbol of the ponderable universe regarded as a whole. Neither object can be presented to the imagination, but, nevertheless, they are to be treated as realities in the order of ideas, and appear in the chemical system as the necessary limits of our conceptions.

(4) Similar ideas occur in every symbolic method. In symbolic chemistry 1, as the symbol of the unit of space, the subject of chemical operations, occupies the place held in the geometric calculus by 1, the symbol of the unit of length considered as the subject of the operations of geometry. Again, the chemical symbol ∞ holds a position analogous to that occupied by the symbol 1 in the calculus of probabilities, as denoting the total subject matter of the science, and the chemical symbols 1 and ∞, the symbols of space and of the ponderable universe, represent in the calculus of chemistry the limits between which the values of all other symbols are comprised, precisely as in arithmetical algebra the corresponding limits are represented by the symbols 0 and ∞, and in the calculus of logic by the symbols 0 and 1[*].

---

[*] BOOLE, 'Laws of Thought,' p. 47.

SECTION IV.—ON THE FUNDAMENTAL CHEMICAL EQUATIONS.

(1) xy is the symbol of a single weight which is composed of the same weights as those of which that group of weights is constituted of which $x+y$ is the symbol. Now according to the definition which I have given of chemical identity, two weights are said to be identical which consist of the same weights (Sec. I. Def. 6). Hence the weight of which xy is the symbol is identical with the weight of which $x+y$ is the symbol; and

$$xy=x+y.$$

In like manner, since $\frac{x}{y}$ is the symbol of a single weight composed of the same weights as that of which the group of weights $x-y$ is constituted,

$$\frac{x}{y}=x-y.$$

These equations may justly be termed the fundamental equations of the Chemical Calculus, for from them chemical symbols derive their distinctive character, and, through the limitations thus imposed upon them, are discriminated from numerical symbols, which in many respects they resemble*.

(2) If, in the equation $xy=x+y$, $y=1$, $x1=x+1$; whence since $x=x1$ and $x-x=0$, we infer that

$$0=1.$$

This equation informs us of the identity of the ponderable matter of which 0 and 1 are the symbols, which has already been shown.

The same point may be proved in a similar manner as regards the other forms of the symbol 1. For since

$$x-x=x-1x,$$

$$x-x=xx^{-1},$$

and

$$0=x^0.$$

Or, since

$$mx=x^m,$$

$$0=x^0.$$

And again, since

$$\frac{x}{y}=x-y,$$

---

* This equation occupies a somewhat similar place in the chemical calculus to that held in the logical system by the equation $x^2=x$ (BOOLE, 'Laws of Thought,' p. 31), as being expressive of a characteristic property by which the symbols are distinguished. The possibility of the existence of a class of symbols, other than the symbols of the logarithms of numbers, which should satisfy the condition

$$f(x)+f(y)=f(xy),$$

was indicated by D. F. GREGORY in his paper "On the Real Nature of Symbolical Algebra" (Edin. Phil. Trans. vol. xiv. p. 208). This anticipation is here realized.

if $y=x$,

$$\frac{x}{x}=x-x,$$

and

$$\frac{x}{x}=0.$$

We thus arrive from the general properties of chemical symbols at the same result as regards the forms of the symbol 1, and the interpretation of that symbol, as was inferred from the special interpretations of each form of that symbol.

(3) If, in the equation $xy=x+y$, $x=1$ and $y=1$,

$$1^2=1+1$$

and

$$1=2.$$

From this and the previous equation, $0=1$, it is to be inferred that

$$0=1=2=3=\ldots\ldots n.$$

It hence follows that any number of numerical symbols of this class may be added to a chemical function without affecting its interpretation; a property which will hereafter be shown to admit of important applications. The reason of this is that in every independent symbol of number which enters into a chemical function the chemical symbol 1 is understood as the subject of operation, so that $2=2\times1$, and that this symbol has no interpretation in weight. We have a parallel to this property of chemical symbols in the property conferred upon numerical symbols by the factor 0, where

$$0=1\times0=2\times0=3\times0=\ldots\ldots n\times0.$$

The chemical equation $0=1$ may at the first glance appear paradoxical. But this apparent paradox arises merely from the associations connected with the interpretation of these symbols in those symbolic systems with which we are most familiar. In these systems there is a profound antithesis between the symbols, which reaches its climax in the logical system, where 0 is the symbol of nothing and 1 the symbol of the universe of thought*. It need not, however, be a matter of surprise that in the chemical system we should have two symbols for "no weight," since in that system the same ponderable matter may be denoted by xy and $x+y$. Indeed it might even be expected from analogy that as a real weight may have several symbols, so the absence of weight should be expressed in more than one way. Nor is it, in truth, more singular or paradoxical that in chemistry 0 and 1 should be symbols denoting the same object, than that in geometry x^0 and 1 should have the same interpretation.

Now it would appear that the symbols 0 and 1 may occur in a chemical function with two distinct interpretations, as chemical symbols and as arithmetical symbols, and that to prevent ambiguity, it might be desirable to make evident by some special notation the meaning to be assigned to them. But this is not necessary. The chemical symbol 1, although implicitly contained as the subject of operations in every chemical function, yet conformably to the principles of algebraic notation may be invariably suppressed, and every numerical symbol which appears in this calculus may be interpreted with its usual arithmetical signification, regard being had to those special properties which are derived from the subject on which it operates. If, for a moment, we discriminate between the chemical and arithmetical symbols 0 and 1, marking the former as $0'$ and $1'$, and the latter as (0) and (1), it is at once evident that $(1)=(1)1'=1'$, and that $(0)=(0)x=0'$. Hence we may in every case replace the chemical symbols $0'$ and $1'$ by the arithmetical symbols (0) and (1), which are, so far as the purposes of this calculus are concerned, identical with them both in interpretation and in properties. These symbols 0 and 1 may be termed the zero-symbols of the chemical system, being marks by which we denote the absence of ponderable matter. That such symbols may serve most important ends is evident from the use which has been made in arithmetic of the zero-symbol 0, which is the very key-stone of the arithmetical system; and yet it is not too much to assert that the system of chemical symbols without the zero-symbol 1 is as incomplete and as little adapted to the purpose which it is destined to fulfil as the arithmetical system would be deprived of the symbol 0.

---

* BOOLE, 'Laws of Thought,' p. 48.

(4) No other known system of symbols is characterized by the same property as that by which chemical symbols are defined, but the equation $x+y=xy$ is similar in form to the equation connecting the logarithms of numbers; and the relation which subsists between the absolute weight (or weight in grammes) of the ponderable matter of which x and y are the symbols is the same as the logarithmic relation. For, writing $w(x)$ and $w(y)$ as the absolute weights of the ponderable matter symbolized by x and y,

$$w(x)+w(y)=w(xy),$$
$$w(1)+w(y)=w(y),$$
$$w(1)=0,$$

similar in form with the logarithmic equations

$$l(x)+l(y)=l(xy),$$
$$l(1)+l(y)=l(y),$$
$$l(1)=0.$$

The property of chemical symbols given in the equation $x+y=xy$ may from these analogies appropriately be termed the "logarithmic" property of these symbols.

(5) It is sufficiently obvious that we may operate between chemical equations by means of addition and subtraction as with numerical equations. This is a consequence of the axiom that if identical weights be added to or removed from identical groups the resulting groups are identical. So that, if $x=y$, and $x_1=y_1$, $x\pm x_1=y\pm y_1$. The operations, however, which correspond to the algebraic operations of multiplication and division can only be performed under certain conditions, which will be considered in a subsequent part of this memoir.

SECTION V.—ON THE SYMBOLS OF SIMPLE WEIGHTS.

(1) A simple weight has been defined as a weight which is not compound, and two weights as simple in regard to one another which have no common component.

It follows from this definition that the symbol of a simple weight cannot be expressed by more than one factor, and also that the symbols of weights simple in regard to one another cannot have a common factor.

The symbol of a simple weight is termed a prime factor, and the symbols of weights simple in regard to one another are said to be prime to one another.

The symbols of simple weights have the following properties:—

(2) The operations of algebraic subtraction and division cannot be performed between such symbols. For let a and b be two symbols of simple weights, and, if possible, let $a-b=a_1$. Then $a=a_1+b=a_1b$, that is, a is the symbol of a compound weight, which is contrary to the hypothesis.

Or again, if possible, let $\frac{a}{b}=c$. Then $a-b=c$, and $a=b+c=bc$, which is, as before, contrary to the hypothesis.

(3) If a and b be two symbols of weights simple in regard to one another, and if $aa_1=bb_1$, then

$$a_1=bk, \text{ and } b_1=ak;$$

for since $aa_1=bb_1$, $a+a_1=b+b_1$, and $a_1=b+b_1-a$; and since by hypothesis b is the symbol of a weight simple in regard to a, no part of a is a constituent of b, therefore a must be a constituent of b_1, so that $b_1=a+k$ and $a_1=b+k$. Whence also $b_1=ak$, and $a_1=ak$.

(4) Hence also if a_1 be the symbol of a weight simple in regard to the weights a and b, a_1 is the symbol of a weight simple in regard to the weight ab.

For otherwise, if possible, let a_1 and ab have a common component k, so that $a_1=ck$, and $ab=c_1k$; then, since by hypothesis k is a factor of a_1, k is by hypothesis prime to a. Therefore k is a factor of b, which is also contrary to the hypothesis.

We may also argue thus. If possible, let k be the factor common to a_1 and ab. Then $ab=kd$, and $d=a+b-k$. But by hypothesis no part of k is a constituent of a; therefore k is a constituent of b, and $b=k+c=kc$, which is contrary to the hypothesis.

(5) Hence if a is prime to b, a^p is prime to b^q, and no part of qb is a constituent of pa.

(6) Also, if $a, b, c, d, \ldots..$ be prime to $a_1, b_1, c_1, d_1, \ldots..$, then $a^pb^{p_1}c^{p_2}d^{p_3} \ldots..$ is prime to $a^qb^{q_1}c^{q_2}d^{q_3} \ldots..$; and also the operation of subtraction cannot be performed between the weights $pa+p_1b+p_2c+p_3d+\ldots...$ and $qa_1+q_1b_1+q_2c_1+q_3d_1+\ldots..$

(7) Whence, if $a, b, c, d, \ldots..$ be symbols prime to one another, and if

$$a^pb^{p_1}c^{p_2}d^{p_3} \ldots.. =1,$$

$$p=0, p_1=0, p_2=0, p_3=0 \ldots..;$$

nd if

$$pa+p_1b+p_2c+p_3d+\ldots\ldots=0,$$
$$p=0, p_1=0, p_2=0, p_3=0\ldots\ldots$$

(8) Lastly, a composite symbol can only be expressed in one manner by means of prime factors. That is to say, a compound weight can only be assumed to be composed of one set of simple weights. This proposition may be proved in the same manner as the corresponding numerical proposition.

This assertion does not imply that we cannot make more than one hypothesis as to the expression of any given composite symbol by means of prime factors, that is, as to the simple weights of which a given compound weight is composed, but only that two or more such hypotheses cannot simultaneously be true.

There is a close analogy between the symbols of simple weights in chemistry and the symbols of prime numbers in arithmetic, but owing to the condition imposed on chemical symbols, given in the equation $x+y=xy$, a chemical symbol which has only one factor is also incapable of partition.

The prime symbols of chemistry may be indifferently defined by either property, the one being a consequence of the other, and constitute a new and peculiar order of symbols. There is, however, one numerical symbol of the class, namely, the symbol 1, which has only one factor and one part, and like the primes of chemistry is incapable of division or partition.

(9) An integral compound weight has been defined (Sec. I. Def. 9) as a weight which is composed of an integral number of simple weights. If ϕ be the symbol of such a weight, $a, b, c, \ldots\ldots$, as before, the symbols of simple weights, and $n, n_1, n_2, \ldots\ldots$ integral numbers,

$$\phi=a^nb^{n_1}c^{n_2}\ldots\ldots$$

This symbol is termed an integral composite symbol. It is identical in form with the symbol of an integral number expressed by means of its prime factors.

(10) It remains to consider the method by which we may arrive at the expression of chemical symbols by means of an integral number of prime factors in a given system of equations, if such an expression be possible, and further may select from the various forms of symbols which satisfy this condition that form in which the symbols are expressed by the smallest possible number of such factors. In this form the symbol is said to be expressed in the simplest possible manner by means of prime factors, it being the only symbolic expression which is at once both necessary and sufficient to satisfy the conditions of the problem.

To these conditions it is to be added that the prime factors thus chosen are to be the symbols of real weights, it being possible to find symbolic expressions which satisfy the requirements of the equation, but which do not admit of interpretation, the weights of which they are the symbols being affected with the negative sign. Such expressions will here be rejected.

Now, first let the system of equations in which it is required to express the chemical symbols by means of prime factors consist of one equation, and, to render the problem determinate, let the equation contain only two undetermined symbols, and be of the form

$$m\varphi+m'\varphi_1+m''\varphi_2=0,$$

where m, m', m'' are known, being positive or negative numerical symbols; and let $\varphi_2=a^nb^{n_1}$, a and b being the symbols of simple weights, and n, n_1 given positive and integral numbers.

Then putting $\varphi=a^pb^{p_1}$, $\varphi_1=a^qc^{q_1}$,

$$ma^pb^{p_1}+m'a^qb^{q_1}+m''a^nb^{n_1}=0,$$

whence, from the fundamental equation $x+y=xy$,

$$(a^pb^{p_1})^m(a^qb^{q_1})^{m'}(a^nb^{n_1})^{m''}=1,$$

and from the property of simple weights before given (Sec. V. (7))

$$mp+m'q+m''n=0,$$

$$mp_1+m'q_1+m''n_1=0.$$

The integral and positive solutions of these equations as regards p, q, p_1, q_1, if such can be found, will give all the possible ways by which the symbols φ and φ_1 can be expressed by means of prime factors in the above equation, the symbol φ_2 being of the form given, and the minimum solution in whole numbers of these equations, as regards the same indeterminate quantities, will give the simplest expression of the symbols by means of prime factors, subject to the same condition.

The number of admissible forms of these symbols is, however, further limited by the requirement that the factors a and b are to be the symbols of real weights.

Putting W, W_1, W_2 as the known absolute weights of the portions of matter of which φ, φ_1, φ_2 are the symbols, and $w(a)$, $w(b)$ as the unknown absolute weights of the simple weights of which a and b are the symbols, we have for the determination of $w(a)$ and $w(b)$ the equations

$$pw(a)+p_1w(b)=\text{W},$$

$$qw(a)+q_1w(b)=\text{W}_1,$$

$$nw(a)+n_1w(b)=\text{W}_2,$$

which, subject to the equation of condition

$$m\text{W}+m'\text{W}_1+m''\text{W}_2=0,$$

are equivalent to two independent equations. All values, therefore, of p, p_1, q, q_1 are to be rejected which would give a negative value for $w(a)$ or $w(b)$ in the above equations.

If in the original equation the given symbol φ_2 be expressed by more than two factors, so that $\varphi_2=a^nb^{n_1}c^{n_2}$, the problem is indeterminate unless the absolute weight of one of the simple weights be given; for in this case we should have only two equations to determine the three values $w(a)$, $w(b)$, $w(c)$.

Or again, if no symbol were given, so that $\varphi_2=a^rb^{r_1}$, r and r_1 being indeterminate quantities, the indeterminate equations, whence the value in whole numbers of p, p_1, q, q_1, r, r_1 are to be ascertained, become

$$mp\ +m'q\ +m''r\ =0,$$
$$mp_1+m'q_1+m''r_1=0,$$

the two equations containing three indeterminate quantities.

If in the original equation two symbols were given as determined from other considerations, as that

$$\varphi_2=a^s b^{s_1},$$
$$\varphi_1=a^t\, b^{t_1},$$

s, s_1, t, t_1 being given positive and integral, the indeterminate equations would contain only one unknown quantity, and the problem would be possible in that case alone where the values of p and p_1 derived from them were positive and integral, and where the conditions before referred to and given in the equations connecting $w(a)$ and $w(b)$ were satisfied.

The course to be pursued in other cases is sufficiently obvious from the above instance. It remains only to state the nature of the problem in its most general form.

If there be a system of N equations connecting the chemical symbols $\varphi, \varphi_1, \varphi_2, \varphi_3, \ldots\ldots$ of the form

$$m\varphi+m'\varphi_1+m''\varphi_2+m'''\varphi_3+\ldots\ldots=0,$$

where $m, m', m'', \ldots$ are numerical symbols, negative, positive, or 0, putting as before

$$\varphi\ =a^p b^{p_1} c^{p_2}\ldots\ldots,$$
$$\varphi_1=a^q\, b^{q_1} c^{q_2}\ldots\ldots,$$
$$\varphi_2=a^r\, b^{r_1} c^{r_2}\ldots\ldots,$$

we shall have N sets of indeterminate equations connecting $p, q, r, \ldots$ and $p_1, q_1, r_1, \ldots$ and $p_2, q_2, r_2, \ldots$ of the form

$$mp\ +m'q\ +m''r\ +\ldots\ldots=0,$$
$$mp_1+m'q_1+m''r_1'+\ldots\ldots=0,$$
$$mp_2+m'q_2+m''r_2+\ldots\ldots=0,$$
$$\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$
$$\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot$$

If a common positive solution in whole numbers of these N sets of equations for

$$p, q, r, \ldots\ldots, \quad p_1, q_1, r_1, \ldots\ldots, \quad p_2, q_2, r_2, \ldots\ldots$$

can be found, then the symbols $\varphi, \varphi_1, \varphi_2, \ldots\ldots$ can be expressed in the given system of equations by means of the prime factors $a, b, c, \ldots\ldots$; if such a solution does not exist, then the symbols cannot be so expressed; and the simplest expression of the symbols $\varphi, \varphi_1, \varphi_2$ in that system of equations by means of the prime factors $a, b, c, \ldots\ldots$ is that expression in which the indices $p, p_1, p_2, \ldots\ldots, q, q_1, q_2, \ldots\ldots, r, r_1, r_2, \ldots\ldots$ have the minimum integral values which satisfy the above N sets of indeterminate equations.

The admissible values are limited by the conditions

$$\begin{aligned} pw(a)+p_1w(b)+p_2w(c)\ldots\ldots &=\mathrm{W}, \\ qw(a)+q_1w(b)+q_2w(c)\ldots\ldots &=\mathrm{W}_1, \\ rw(a)+r_1w(b)+r_2w(c)\ldots\ldots &=\mathrm{W}_2, \\ \cdots\cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots\cdots \end{aligned}$$

where $w(a)$, $w(b)$, $w(c)$ are positive, and $\mathrm{W}, \mathrm{W}_1, \mathrm{W}_2, \ldots\ldots$ are connected by N equations of the form

$$m\mathrm{W}+m'\mathrm{W}_1+m''\mathrm{W}_2+m'''\mathrm{W}_3+\ldots\ldots=0.$$

SECTION VI.—ON THE CONSTRUCTION OF CHEMICAL EQUATIONS FROM THE DATA AFFORDED BY EXPERIMENT.

Our knowledge as to the identical relations of ponderable matter is derived, as has already been observed, exclusively from the science of chemistry. The next step in this inquiry is to embody in a system of chemical equations the information on this subject which experiment affords to us. The process is very simple by which this may be effected. To take, for example, a single instance. Let it be supposed that we have ascertained by experiment that 3000 cub. centims. of chlorine and 2000 cub. centims. of ammonia have been converted into 6000 cub. centims. of hydrochloric acid and 1000 cub. centims. of nitrogen. We hence infer the identity of the ponderable matter of which the two groups respectively consist, and putting

φ as the symbol of a unit of chlorine,
φ_1 as the symbol of a unit of ammonia,
φ_2 as the symbol of a unit of hydrochloric acid,
φ_3 as the symbol of a unit of nitrogen,

we assert this identity in the chemical equation

$$3\varphi+2\varphi_1=6\varphi_2+\varphi_3.$$

Proceeding in other cases in a similar manner, we should arrive at a system of equations corresponding in number to the experiments of which the results were thus recorded. It would soon, however, be perceived that we could not in this manner indefinitely add to our knowledge, but that the information thus supplied to us was soon exhausted, the equations not being independent, but capable of being derived from one another by the processes of addition and subtraction; and that, in fact, they could be replaced by a single system of equations connecting every chemical symbol equal in number to the total number of chemical substances, exclusive of the elemental bodies. Such a system is afforded to us by those equations which express the relations of identity which subsist between the ponderable matter of compound substances and the ponderable matter of the elemental bodies of which they are composed, which we may consider as a solution of the entire system of chemical equations in regard to the symbols of the elements. From this primary system every other chemical equation may be derived, and our total knowledge as to the identical relations of ponderable matter is implicitly comprised in it. Indeed it may readily be shown that, however numerous may be our experiments, we can never arrive at any greater number of independent equations without effecting the decomposition of the elements. For if such an independent equation were discovered, it either would be an equation connecting the symbols of the elements themselves, or if it contained the symbols of other substances we might eliminate between it and the other equations of the system, and thus derive such an equation. It is possible that the limited range of physical conditions under which we necessarily operate, or other obstacles equally insuperable, may for ever preclude such an addition to our knowledge, but nevertheless we can form a conception of another and a wider chemistry, of which our actual system should be but an imperfect fragment, and in which we should have n independent equations containing $n+1$ symbols admitting of a solution of the form

$$\phi=m\theta,$$

when we should recognize but one primary elemental form of ponderable matter, and the great problem of analysis would be completely and finally resolved.

Every chemical equation is necessarily the expression of a hypothesis; for even the most accurate experiments are attended with error, and can only be regarded as affording a certain approximation to that true result at which it is our object to arrive. Even the assertion that two gaseous volumes of water consist of the same ponderable matter as two volumes of hydrogen and one volume of oxygen involves hypotheses as to the gaseous densities of those substances, and the relations of absolute weight before and after chemical change, which go beyond our actual experience. Experiment proves this proposition to be true within certain limits of error, but in the equation

$$2\phi=2\phi_1+\phi_2,$$

an assertion is made in which the errors of observation are not included. Regard being had to the total evidence on which it rests, no statement of the kind is perhaps more credible than this; and the above equation may serve to mark the extreme limit to which chemical certainty has attained. Such equations form the true basis of the science.

It is, however, only in comparatively few instances that we are able to ascertain by direct observation the gaseous densities of all the chemical substances which enter into a reaction; and where this cannot be effected we are compelled to have recourse to indirect methods of a less satisfactory character, to attain the desired end.

There are many admirable examples of such chemical reasoning*, which, divested of the theoretical considerations with which they are unnecessarily complicated, may be regarded as arguments based upon actual observation of the laws of chemical change, by which certain forms of these equations are established with superior probability, to the exclusion of other forms. The conclusions thus arrived at must obviously have very different values, and while some are in the highest degree probable, others can only be regarded as tentative and conjectural. But, nevertheless, uncertain as such results may often appear, a profound distinction is to be drawn between this order of hypothesis and those molecular speculations which can neither be confirmed nor disproved by facts. In the former case experiment is constantly controlling our conclusions, and we have the most positive evidence that the methods pursued by the chemist are in the main correct; since in numerous cases he has been able to anticipate the results of direct observation, and in others even to correct by theory the erroneous results which observation apparently afforded.

---

* For example, ODLING "On the Atomic Weight of Oxygen and Water," Journal of the Chemical Society, vol. xi. p. 107. Also the article in WATTS's Dictionary of Chemistry by the same author on the atomic weights of the metals; and WURTZ, "On the Oxide of Ethylene considered as a link between Organic and Inorganic Chemistry," Journal of the Chemical Society, vol. xv. p. 387.

It is essential to have clear ideas upon this point, that we may not over-estimate the value of our results, since any uncertainty attached to the data must undoubtedly attend the conclusions which are derived from them; but nevertheless the question does not fall within the scope of a deductive and symbolic method, the province of which commences only where the task of experiment terminates; and in the consideration of chemical equations I have not, in uncertain cases, attempted any full discussion of the evidence on which they rest, but have limited myself to arguments, in regard to which the application of symbolic reasoning afforded some peculiarity or advantage.

SECTION VII.—ON THE SYMBOLS OF THE UNITS OF CHEMICAL SUBSTANCES.

Group 1.—*Symbols of Hydrogen, Oxygen, Sulphur, Selenium, Chlorine, Iodine, Bromine, Nitrogen, Phosphorus, Arsenic, and Mercury.*

(1) *Symbol of Hydrogen.*—I am about to show by the aid of the principles which have been established in the previous pages that the units of chemical substances are composed of an integral number of simple weights; that is to say, according to the definition previously given (Sec. I. Def. 9 & 10), that these units are "integral compound weights." The point will be demonstrated if it be found possible to express the symbols of these units in the actual system of chemical equations by means of an integral number of prime factors, these factors being the symbols of real weights (Sec. V. (9 & 10)). Now it will be found that such an expression is not only possible, but possible in a great variety of ways; in other words, many assumptions may be made as to the composition of ponderable matter which are consistent with the above fundamental hypothesis. From these possible expressions, that one will in each case be selected, as the correct inference from the facts, in which the symbol is expressed by the smallest possible number of such factors; since any other expression, as has before been indicated, must involve hypotheses which are unnecessary.

The problem is not dissimilar to that of the determination of the density or relative weight of the same units. We are about to estimate the number and the absolute weight of the simple weights of which the units (Sec. I. Def. 8 & 10) of ponderable matter are composed; and, as in the former case the problem is unmeaning unless the standard of absolute or relative weight be previously determined, so in the latter case also it is necessary that some one simple weight shall be selected from external considerations as the standard of comparison, before any statement can be made upon the subject. This case, however, differs from the preceding in the circumstance that the selection of a simple weight is not the choice of an arbitrary unit, to be determined by considerations of convenience alone, but involves the assertion of a hypothesis as to the actual composition of the chemical units of ponderable matter, which may be verified and tested by experience.

Now the hypothesis on which the present method is based, and which is the only assumption of the kind which I shall have occasion to make, is that the unit of hydrogen is a simple weight, that is to say, that in chemical transformations this weight is never distributed (Sec. I. Def. 12). The symbol of this "weight" (Sec. I. Def. 3) will be expressed by the letter α, which may be termed the "modulus" of the symbolic system, it being that symbol by which the form of every other symbol is regulated. The absolute weight of the portion of ponderable matter thus symbolized, that is to say, of 1000 cub. centims. of hydrogen at 0° C. and 760 millims. pressure, is 0·089 grm.

In considering this question I shall select certain examples which may serve to illustrate the way in which the subject may be treated, and the difference in the result arrived at, according to the degree of information supplied to us by experiment.

The first, and for the present object the most important, group of symbols to be considered are the symbols of those elements of which the density in the gaseous condition can be experimentally determined, and which also form with one another gaseous combinations. I shall then consider the symbols of carbon and its combinations with the previous group, and subsequently the symbols of certain other elements and their combinations as to which we possess less adequate information.

(2) *Symbol of Oxygen.*—It is known from experiment that 2 units of water can be decomposed into 2 units of hydrogen and 1 unit of oxygen. We hence infer the identity of the weights of which these portions of ponderable matter consist, and putting

φ as the symbol of the unit of water,
φ_1 as the symbol of the unit of hydrogen,
φ_2 as the symbol of the unit of oxygen,

$$2\varphi=2\varphi_1+\varphi_2.$$

Now, if possible, let

$$\varphi=\alpha^m\xi^{m_1},$$
$$\varphi_1=\alpha,$$
$$\varphi_2=\alpha^n\xi^{n_1},$$

where α and ξ are prime factors, that is to say, the symbols of simple weights, and m, m_1, n, n_1 positive integers. Then

$$2\alpha^m\xi^{m_1}=2\alpha+\alpha^n\xi^{n_1},$$

and from the fundamental equation which connects chemical symbols, $x+y=xy$ (Sec. IV. (1)),

$$(\alpha^m\xi^{m_1})^2=\alpha^2\alpha^n\xi^{n_1},$$

whence

$$2m=2+n \text{ and } 2m_1=n_1,$$

to which is attached the condition

$$w(\alpha)=1,$$

$$m+m_1w(\xi)=9;$$

1 and 9 being the densities of hydrogen and of water, and $w(\alpha)$ and $w(\xi)$ being positive.

The integral and positive solutions of these equations as regards m, m_1, n, n_1, give all the possible hypotheses which can be made as to the components of oxygen and of water, which are consistent with the hypothesis that the unit of each of these substances is composed of an integral number of simple weights, and that the unit of hydrogen is a simple weight, and the minimum solution selects from these that one hypothesis which is both necessary and sufficient to satisfy the condition given in the equation

$$2\varphi=2\varphi_1+\varphi_2.$$

This solution is

$$n=0, \quad m=1,$$

$$n_1=2, \quad m_1=1,$$

whence the symbols of water and oxygen as determined from considering the above equation are

Symbol of water $\alpha\xi$,

Symbol of oxygen ξ^2,

and the relative weights corresponding to the prime factors α and ξ are

$$w(\alpha)=1,$$

$$w(\xi)=8,$$

the equation being thus expressed,

$$2\alpha\xi=2\alpha+\xi^2.$$

It is not to be assumed without proof that these symbols will satisfy the conditions afforded by other equations. This is a matter for inquiry. But we have arrived at the knowledge that no symbol can be found for these substances composed of a smaller number of prime factors, and also that if these symbols can be so expressed the indices of these factors will be found among the integral solutions of the above equations, which are given in the forms

$$m=1+t, \quad n=2t,$$

$$m_1=1+t_1, \quad n_1=2(1+t_1).$$

Hence we arrive at the following general forms for the symbols of oxygen and water,

Oxygen $\alpha^{2t}\xi^{2(1+t_1)}$,

Water $\alpha^{1+t}\xi^{1+t_1}$,

which include all the possible forms of symbols which satisfy the above conditions.

From the equation

$$m+m_1w(\xi)=9$$

we have, substituting for m and m_1 the above values,

$$w(\xi)(1+t_1)=8-t,$$

whence t is not greater than 8. If $t=8$, either $w(\xi)=0$ and $\xi=1$ (Sec. III. (1)), or $t_1=-1$, when $n_1=0$, and $m_1=0$; in which case $w(\xi)=\frac{0}{0}$ and may have any value. In either case we have

Symbol of oxygen α^{16},
Symbol of water α^{9}.

In this case, therefore, owing to the peculiar numerical relation which subsists between the densities, it is possible to express all the symbols by means of the one factor α. The different forms of symbol are given by assigning to t and t_1 all possible values; thus, for example,

		Symbol.	
		Oxygen.	Water.
$t=0$	$t_1=0$	ξ^2	$\alpha\xi$
	$t_1=1$	ξ^4	$\alpha\xi^2$
	$t_1=2$	ξ^6	$\alpha\xi^3$
	. . . . . .	. . . . . .	. . . . . .
$t=1$	$t_1=0$	$\alpha^2\xi^2$	$\alpha^2\xi$
	$t_1=1$	$\alpha^2\xi^4$	$\alpha^2\xi^2$
	$t_1=2$	$\alpha^2\xi^6$	$\alpha^2\xi^3$
	. . . . . .	. . . . . .	. . . . . .
$t=2$	$t_1=0$	$\alpha^4\xi^2$	$\alpha^3\xi$
	$t_1=1$	$\alpha^4\xi^4$	$\alpha^3\xi^2$
	$t_1=2$	$\alpha^4\xi^6$	$\alpha^3\xi^3$
	. . . . . .	. . . . . .	. . . . . .
$t=3$	$t_1=0$	$\alpha^6\xi^2$	$\alpha^4\xi$
	$t_1=1$	$\alpha^6\xi^4$	$\alpha^4\xi^2$
	$t_1=2$	$\alpha^6\xi^6$	$\alpha^4\xi^3$
. . .	. . . . . .	. . . . . .	. . . . . .
. . .	. . . . . .	. . . . . .	. . . . . .
. . .	. . . . . .	. . . . . .	. . . . . .
$t=7$	$t_1=0$	$\alpha^{14}\xi^2$	$\alpha^8\xi$
	$t_1=1$	$\alpha^{14}\xi^4$	$\alpha^8\xi^2$
	$t_1=2$	$\alpha^{14}\xi^6$	$\alpha^8\xi^3$
	. . . . . .	. . . . . .	. . . . . .
$t=8$	$t_1=-1$	α^{16}	α^9

The problem before us is the selection from this system of symbols of that symbol for oxygen (if such can be found) which shall satisfy the conditions afforded by the other equations of the system, and in which it shall be expressed by the smallest possible number of prime factors. Our hypothesis must be necessary as well as sufficient. Owing to the peculiar and simple laws which prevail in the actual system of chemical changes this selection is attended with no difficulty. It will be found by trial that the symbol of oxygen, ξ^2, that symbol in which it is expressed by the smallest number of prime factors in the above equation, will satisfy all other known conditions.

There is only one other known compound of oxygen and hydrogen, the peroxide of hydrogen. Our knowledge as to this substance is very imperfect, but let us assume that it can be decomposed with the formation of water and oxygen, in the ratio of two units of water to one of oxygen. Then putting z as the unknown number of the volumes of the peroxide decomposed, and y as the number of volumes of oxygen formed, and ϕ_3 as the symbol of peroxide of hydrogen,

$$z\phi_3=2y\phi+y\phi_2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

whence, substituting for ϕ its value $\phi_1+\frac{\phi_2}{2}$,

$$z\phi_3=2y\phi_1+2y\phi_2;$$

and putting $\alpha^p\xi^{p_1}$ as the symbol of the peroxide of hydrogen, α as the symbol of hydrogen, and ξ^2 of oxygen,

$$z\alpha^p\xi^{p_1}=2y\alpha+2y\xi^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and

$$(\alpha^p\xi^{p_1})^z=\alpha^{2y}(\xi^2)^{2y},$$

whence

$$zp=2y,$$

$$zp_1=4y.$$

Now, if p and p_1 be positive integers, since z is prime to y, z must be either 1 or 2. If

$$z=1,\ p=2y,\ p_1=4y;$$

if

$$z=2,\ p=y,\quad p_1=2y.$$

In either case the above equation (2) is of the form

$$(\alpha\xi^2)^{y_1}=y_1(\alpha+\xi^2).$$

Now, although it undoubtedly cannot be considered that this equation is established with the same certainty as the equation

$$2\alpha\xi=2\alpha+\xi^2,$$

yet regarded as a question of probability the evidence in favour of this view is very conclusive. For the only hypotheses involved in it are (1) that in this equation the symbol of the peroxide of hydrogen can be expressed by an integral number of prime factors, and (2) that the symbol of hydrogen can be expressed as α, and the symbol of oxygen as ξ^2, in favour of which hypotheses we have (as will hereafter be seen) the evidence of an extensive and uniform experience.

We may proceed by the aid of further hypotheses, and still with great probability, to determine the value of y_1 in this symbol. The most probable hypothesis is that $y_1=1$, and that the symbol of peroxide of hydrogen is $\alpha\xi^2$, in which case the above equation is thus expressed,

$$\alpha\xi^2=\alpha+\xi^2.$$

The chief arguments by which this view is supported are derived from the observations (1) that it is very rarely that the indices of the prime factors of chemical symbols have a common measure; (2) that on this assumption the symbols of hydrogen, water, and peroxide of hydrogen constitute a series of the form α, $\alpha\xi$, $\alpha\xi^2$; and that the densities of these substances form an arithmetical progression, being 1, 9, 17; and that such series so frequently occur in the actual system of chemical symbols as to render probable their existence in the future system.

The conclusions at which we thus arrive are not to be regarded as necessarily final. Not only is it possible that further information as to the chemical properties of the peroxide of hydrogen might lead us to the adoption of a more complex symbol, but we can even specify the very facts, the discovery of which would induce us to modify our opinion. But, nevertheless, the choice of the expression $\alpha\xi^2$ as the symbol of the unit of this substance is not an arbitrary and conventional selection. It expresses the most probable opinion which, with our actual knowledge, we can form as to the nature of the equation from which it is derived, and which we provisionally embody in the symbol for the purpose of tracing the consequences of our hypothesis.

The weight of that portion of any chemical substance which I have termed the chemical unit of ponderable matter, is (Sec. I. Def. (10)) the weight of that portion of each substance which in the gaseous condition, at 0° C. and 760 millims. pressure, occupies the space of 1000 cub. centims. This weight may be measured in two ways; either by comparison with the weight of a cubic centimetre of distilled water at 4° C., or by comparing it with the weight of the chemical unit of hydrogen. We shall hence have two series of numbers by which the weights of the portions of ponderable matter resulting from any chemical operation are expressed, viz.

1. The absolute weight in grammes.
2. The relative weight or density as compared with the weight of the unit of hydrogen.

This second series of numbers may also be regarded as expressing the absolute weight of the units of ponderable matter as estimated in "criths"[*].

Combinations of the Prime Factors α and ξ.

Name of substance.	Prime factors.	Absolute weight, in grammes.	Relative weight.
	α	0·089	1
	ξ	0·715	8
	Symbol.		
Hydrogen	α	0·089	1
Oxygen[†]	ξ^2	1·430	16
Water	$\alpha\xi$	0·805	9
Peroxide of hydrogen	$\alpha\xi^2$	1·520	17

---

[*] Hofmann, *loc. cit.* (Sec. I. (11)).

[†] In calculating the absolute weight, it is necessary to assume the absolute weight of the gaseous litre at 0° and 760 millims. pressure, of some one substance as accurately determined. The weight of a litre of oxygen is here assumed as the standard, and the other numbers are calculated from it.

(3) *Symbol of Sulphur.*—It has been shown by the recent experiments of Deville and Troost that the density of the vapour of sulphur above a temperature of 860° C. becomes constant, and approximates to 32, the density of hydrogen being 1. This being the case, the ponderable matter of 2 units of sulphide of hydrogen is identical with the ponderable matter of 2 units of hydrogen and 1 unit of sulphur. Hence, putting $\alpha^m\theta^{m_1}$ as the symbol of sulphide of hydrogen, and $\alpha^n\theta^{n_1}$ as the symbol of sulphur,

$$2\alpha^m\theta^{m_1}=2\alpha+\alpha^n\theta^{n_1},$$

and

$$(\alpha^m\theta^{m_1})^2=\alpha^2\alpha^n\theta^{n_1},$$

and

$$2m=2+n, \quad 2m_1=n_1,$$

whence

$$n=0, \quad m=1,$$
$$n_1=2, \quad m_1=1,$$

a minimum.

And putting the density of sulphide of hydrogen as 17,

$$m+m_1w(\theta)=17,$$

and

$$w(\theta)=16.$$

Hence we have, as satisfying the conditions afforded by the above equation,

Symbol of sulphur . . . . . . θ^2,
Symbol of sulphide of hydrogen $\alpha\theta$.

If we assume the density of sulphur to be correct as determined before the recent experiments referred to, the simplest statement which can be made as to the decomposition of sulphide of hydrogen is, that 6 volumes of sulphide of hydrogen are decomposed into 6 volumes of hydrogen and 1 volume of sulphur-vapour; in which case

$$(\alpha^m\theta_1^{m_1})^6=\alpha^6\alpha^n\theta_1^{n_1},$$

and

$$6m=6+n, \quad 6m_1=n_1,$$

which gives as the minimum solution

$$n=0, \quad m=1,$$
$$n_1=6, \quad m_1=1,$$

and

$$w(\theta_1)=16.$$

Hence

$$\theta_1=\theta.$$

The symbols, therefore, may be in either case expressed by the same prime factors.

In the latter case, we have

Symbol of sulphur . . . . θ^6,
Symbol of sulphide of hydrogen as before $\alpha\theta$.

By similar reasoning to that employed in the determination of the symbol of the peroxide of hydrogen, we arrive at the following symbols.

Combinations of the Prime Factors α, ξ, and θ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	θ	1·43	16
	Symbol.		
Sulphur	θ^2	2·861	32
Protosulphide of hydrogen..	$\alpha\theta$	1·520	17
Bisulphide of hydrogen	$\alpha\theta^2$	2·950	33
Sulphurous anhydride	$\theta\xi^2$	2·861	32
Sulphuric anhydride	$\theta\xi^3$	3·576	40
Sulphurous acid	$\alpha\theta\xi^3$	3·665	41
Sulphuric acid	$\alpha\theta\xi^4$	4·380	49
Nordhausen sulphuric acid	$\alpha\theta^2\xi^7$	7·956	89
Hyposulphurous acid	$\alpha\theta^2\xi^3$	5·095	57
Dithionic acid............	$\alpha\theta^2\xi^6$	7·241	81
Trithionic acid	$\alpha\theta^3\xi^6$	8·671	97
Tetrathionic acid	$\alpha\theta^4\xi^6$	10·101	113
Pentathionic acid	$\alpha\theta^5\xi^6$	11·532	129

(4) *Symbol of Selenium.*—The vapour-density of selenium exhibits similar anomalies to the vapour-density of sulphur. But from the experiments of DEVILLE there can be little doubt that at a sufficiently high temperature it would accord with theory. DEVILLE found for the vapour-density of selenium at 860°, 8·2, and at 1040°, 6·37. On the hypothesis that 2 volumes of selenide of hydrogen are decomposed into 2 volumes of hydrogen and 1 volume of selenium, the vapour-density of selenium would be expressed by the number 5·44. I shall assume this as the correct number.

We have, then, putting $\alpha^m\lambda^{m_1}$ as the symbol of selenide of hydrogen, and $\alpha^n\lambda^{n_1}$ as the symbol of selenium,

$$2\alpha^m\lambda^{m_1}=2\alpha+\alpha^n\lambda^{n_1},$$

whence, as in the two last examples,

$$2m=2+n, \quad 2m_1=n_1,$$

and

$$n=0, \quad n_1=2,$$
$$m=1, \quad m_1=1,$$

a minimum.

Assuming the density of selenide of hydrogen as 41,

$$w(\lambda)=40.$$

Combinations of the Prime Factors α, ξ, θ, and λ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	λ	3·576	40
	Symbol.		
Selenium................	λ^2	7·151	80
Selenide of hydrogen	$\alpha\lambda$	3·665	41
Selenious anhydride	$\lambda\xi^2$	5·006	56
Selenic anhydride	$\lambda\xi^3$	5·721	64
Selenious acid	$\alpha\lambda\xi^3$	5·810	65
Selenic acid	$\alpha\lambda\xi^4$	6·526	73

(5) *Symbol of Chlorine.*—It is ascertained by experiment that 2 volumes of hydrochloric acid can be decomposed into 1 volume of hydrogen and 1 volume of chlorine.

Hence, putting $\alpha^m\chi^{m_1}$ as the symbol of the unit of hydrochloric acid, and $\alpha^n\chi^{n_1}$ as the symbol of the unit of chlorine,

$$2\alpha^m\chi^{m_1}=\alpha+\alpha^n\chi^{n_1},$$

and

$$(\alpha^m\chi^{m_1})^2=\alpha\alpha^n\chi^{n_1};$$

whence

$$2m=1+n,$$
$$2m_1=n_1,$$

and

$$m=1,\quad m_1=1,$$
$$n=1,\quad n_1=2,$$

a minimum.

Since the density of hydrochloric acid is 18·25, we have to determine the absolute weight of the simple weight χ,

$$m+m_1w(\chi)=18{\cdot}25,$$

whence

$$w(\chi)=17{\cdot}25,$$

which gives for the

Symbol of hydrochloric acid $\alpha\chi$,
Symbol of chlorine . . . $\alpha\chi^2$,

in which case the above equation becomes

$$2\alpha\chi=\alpha+\alpha\chi^2.$$

The general solutions of the above equations, which contain all possible values of the indices of the symbols, give

$$m=1+t,\qquad m_1=1+t_1,$$
$$n=1+2t,\qquad n_1=2(1+t_1),$$

whence we arrive at the following general forms,

Hydrochloric acid $\alpha^{1+t}\chi^{1+t_1}$,
Chlorine . . . $\alpha^{1+2t}\chi^{2(1+t_1)}$,

and

$$w(\chi)=\frac{17{\cdot}25-t}{1+t_1};$$

whence

$$t \text{ is not } >17,$$

and

$$t_1 \text{ is not } <0.$$

Combinations of the Prime Factors α, ξ, θ, λ, and χ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	x	1·542	17·25
	Symbol.		
Chlorine	$\alpha\chi^2$	3·173	35·5
Hydrochloric acid	$\alpha\chi$	1·631	18·25
Protoxide of chlorine	$\alpha\chi^2\xi$	3·888	43·5
Teroxide of chlorine	$\alpha\chi^2\xi^3$	5·319	59·5
Tetroxide of chlorine	$\alpha\chi^2\xi^4$	6·034	67·5
Hypochlorous acid	$\alpha\chi\xi$	2·346	26·25
Chlorous acid	$\alpha\chi\xi^2$	3·062	34·25
Chloric acid	$\alpha\chi\xi^3$	3·777	42·25
Perchloric acid	$\alpha\chi\xi^4$	4·492	50·25
Hydrate of chlorine	$\alpha^{11}\chi^2\xi^{10}$	11·219	125·5
Protosulphide of chlorine	$\alpha\chi^2\theta$	4·604	52·5
Bisulphide of chlorine	$\alpha\chi^2\theta^2$	6·034	67·5
Biselenide of chlorine	$\alpha\chi^2\lambda^2$	10·325	115·5
Tetrachloride of selenium	$\alpha^2\chi^4\lambda$	9·922	111
Chlorosulphurous acid	$\alpha\chi^2\theta\xi$	5·319	59·5
Hydrochlorosulphurous acid	$\alpha\chi\theta\xi^3$	5·207	58·25
Chlorosulphuric acid	$\alpha\chi^2\theta\xi^2$	6·034	67·5

(6) *Symbol of Iodine.*—Two volumes of hydriodic acid are decomposed into 1 volume of hydrogen and 1 volume of iodine.

Hence, putting $\alpha^m\omega^{m_1}$ as the symbol of the unit of hydriodic acid, and $\alpha^n\omega^{n_1}$ as the symbol of the unit of iodine,

$$2\alpha^m\omega^{m_1}=\alpha+\alpha^n\omega^{n_1},$$

and

$$(\alpha^m\omega^{m_1})^2=\alpha\alpha^n\omega^{n_1},$$

and

$$2m=1+n,\ 2m_1=n_1,$$

$$m=1,\quad m_1=1,$$

$$n=1,\quad n_1=2,$$

a minimum.

Assuming the density of iodine vapour to be 127,

$$1+2w(\omega)=127,$$

$$w(\omega)=63,$$

and the symbol of hydriodic acid is $\alpha\omega$, and of iodine $\alpha\omega^2$, in which case the above equation is thus expressed,

$$2\alpha\omega=\alpha+\alpha\omega^2.$$

Combinations of the Prime Factors α, ξ, θ, λ, χ, and ω.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ω	5·632	63
	Symbol.		
Iodine	$\alpha\omega^2$	11·353	127
Hydriodic acid	$\alpha\omega$	5·721	64
Iodic anhydride	$\alpha\omega^2\xi^5$	14·928	167
Per-iodic anhydride	$\alpha\omega^2\xi^7$	16·359	183
Iodic acid	$\alpha\omega\xi^3$	7·866	88
Protochloride of iodine	$\alpha\omega\chi'$	7·263	81·25
Terchloride of iodine	α^2	10·436	116·75

(7) *Symbol of Bromine.*—Two volumes of hydrobromic acid are decomposed into 1 volume of hydrogen and 1 volume of bromine.

Hence, putting $\alpha^m\beta^{m_1}$ as the symbol of the unit of hydrobromic acid, and $\alpha^n\beta^{n_1}$ as the symbol of the unit of bromine,

$$2\alpha^m\beta^{m_1}=\alpha+\alpha^n\beta^{n_1},$$

and by similar reasoning to that by which the symbols of chlorine and iodine have been ascertained, we have

Symbol of hydrobromic acid $\alpha\beta$,
Symbol of bromine . . . $\alpha\beta^2$,

and assuming 80 as the density of bromine,

$$w(\beta)=39·5.$$

Combinations of the Prime Factors α, ξ, θ, λ, χ, ω, and β.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	β	3·531	39·5
	Symbol.		
Bromine	$\alpha\beta^2$	7·151	80
Hydrobromic acid	$\alpha\beta$	3·620	40·5
Protoxide of bromine	$\alpha\beta^2\xi$	7·866	88
Hypobromous acid	$\alpha\beta\xi$	4·335	48·5
Bromic acid	$\alpha\beta\xi^3$	5·766	54·5

(8) *Symbol of Nitrogen.*—Two volumes of ammonia can be decomposed into 3 volumes of hydrogen and 1 volume of nitrogen.

Hence, putting $\alpha^m\nu^{m_1}$ as the symbol of the unit of ammonia, and $\alpha^n\nu^{n_1}$ as the symbol of the unit of nitrogen,

$$2\alpha^m\nu^{m_1}=3\alpha+\alpha^n\nu^{n_1},$$

and

$$(\alpha^m\nu^{m_1})^2=\alpha^3\alpha^n\nu^{n_1};$$

whence

$$2m=3+n, \quad 2m_1=n_1,$$

and

$$m=2,\quad m_1=1,$$
$$n=1,\quad n_1=2,$$

a minimum.

Hence the symbol of nitrogen as determined from this equation is $\alpha\nu^2$, and the symbol of ammonia is $\alpha^2\nu$.

Since the density of ammonia is 8·5,

$$2+w(\nu)=8{\cdot}5,$$

and

$$w(\nu)=6{\cdot}5.$$

The general solutions of the above equations give

$$m=2+t,\quad m_1=1+t_1,$$
$$n=1+2t,\quad n_1=2(1+t_1),$$

whence we have as the

Symbol of ammonia . . . $\alpha^{2+t}\nu^{1+t_1}$,
Symbol of nitrogen . . . $\alpha^{1+2t}\nu^{2(1+t_1)}$,

and

$$w(\nu)=\frac{6{\cdot}5-t}{1+t_1},$$

where t is not >6, and t_1 not <0.

Combinations of the Prime Factors α, ξ, θ, χ, λ, ω, β and ν.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ν	0·581	6·5
	Symbol.		
Nitrogen	$\alpha\nu^2$	1·251	14
Ammonia	$\alpha^2\nu$	0·760	8·5
Protoxide of nitrogen	$\alpha\nu^2\xi$	1·967	22
Binoxide of nitrogen*	$\alpha\nu^2\xi^2$	2·682	30
Teroxide of nitrogen	$\alpha\nu^2\xi^3$	3·397	38
Tetroxide of nitrogen	$\alpha\nu^2\xi^4$	4·112	46
Pentoxide of nitrogen	$\alpha\nu^2\xi^5$	4·827	54
Nitrous acid	$\alpha\nu\xi^2$	2·101	23·5
Nitric acid	$\alpha\nu\xi^3$	2·816	31·5
Bisulphide of nitrogen	$\alpha\nu^2\theta^2$	4·112	46
Chloride of nitrogen	$\alpha^2\nu\chi^3$	5·386	60·25
Nitrite of ammonium	$\alpha^3\nu^2\xi^2$	2·861	32
Nitrate of ammonium	$\alpha^3\nu^2\xi^3$	3·576	40
Sulph-hydrate of ammonium	$\alpha^3\nu\theta$	2·279	25·5
Protosulphide of ammonium	$\alpha^5\nu^2\theta$	3·039	34
Bisulphide of ammonium	$\alpha^5\nu^2\theta^2$	4·470	50
Acid sulphite of ammonium	$\alpha^3\nu\theta\xi^3$	4·424	49·5
Acid sulphate of ammonium	$\alpha^3\nu\theta\xi^4$	5·139	57·5
Sulphite of ammonium	$\alpha^5\nu^2\theta\xi^3$	5·285	58
Sulphate of ammonium	$\alpha^5\nu^2\theta\xi^4$	6·000	66
Thionamic acid†	$\alpha^2\nu\theta\xi^2$	3·620	40·5
Sulphamic acid	$\alpha^2\nu\theta\xi^3$	4·336	48·5
Thionamide	$\alpha^3\nu^2\theta\xi$	3·576	40
Sulphamide	$\alpha^3\nu^2\theta\xi^2$	4·281	48
Acid sulphate of azotyl	$\alpha\nu\theta\xi^5$	5·676	63·5
Neutral sulphate of azotyl	$\alpha\nu^2\theta\xi^6$	6·972	78
Anhydro-sulphate of azotyl	$\alpha\nu^2\theta\xi^9$	9·118	102
Chloride of ammonium*	$\alpha^3\nu\chi$	2·391	26·75
Chloride of azotyl†	$\alpha\nu\chi\xi$	2·928	32·75
Chloride of nitryl†	$\alpha\nu\chi\xi^2$	3·642	40·75
Bichloride of azotyl	$\alpha^3\nu^2\chi^2\xi^2$	5·944	66·5
Chlorate of ammonium	$\alpha^3\nu\chi\xi^3$	4·537	50·75
Iodide of ammonium	$\alpha^3\nu\omega$	6·481	72·5
Diniodamide	$\alpha^2\nu\omega^2$	12·023	134·5
Bromide of ammonium	$\alpha^3\nu\beta$	4·380	49

(9) *Symbol of Phosphorus.*—Let the symbol of the unit of phosphorus be $\alpha^n\varphi^{n_1}$, and the symbol of the unit of gaseous phosphide of hydrogen $\alpha^m\varphi^{m_1}$. Then, since 4 volumes of the gaseous phosphide of hydrogen are decomposed into 6 volumes of hydrogen and

---

* The symbols of nitric oxide, chloride of ammonium, and certain other substances, the densities of which are apparently anomalous, will be subsequently considered (see Section VIII.).

† See ODLING's 'Chemistry,' pages 269, 254, and 261.

1 volume of phosphorus-vapour,

$$4\alpha^{m}\varphi^{m_1}=6\alpha+\alpha^{n}\varphi^{n_1},$$

and

$$(\alpha^{m}\varphi^{m_1})^4=\alpha^6\alpha^{n}\varphi^{n_1},$$

whence

$$4m=6+n, \qquad 4m_1=n_1,$$

and

$$\begin{aligned} m&=2, & m_1&=1, \\ n&=2, & n_1&=4, \end{aligned}$$

a minimum; and we have for the

Symbol of phosphide of hydrogen $\alpha^2\varphi$,
Symbol of phosphorus . . . $\alpha^2\varphi^4$

Assuming the density of phosphorus-vapour as 62,

$$2+4w(\varphi)=62,$$
$$w(\varphi)=15.$$

Combinations of the Prime Factors α, ξ, θ, λ, χ, ω, β, ν, and φ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	φ	1·341	15
	Symbol.		
Phosphorus..............	$\alpha^2\varphi^4$	5·541	62
Phosphide of hydrogen	$\alpha^2\varphi$	1·519	17
Teroxide of phosphorus	$\alpha\varphi^2\xi^3$	4·916	55
Pentoxide of phosphorus ..	$\alpha\varphi^2\xi^5$	6·346	71
Hypophosphorous acid	$\alpha^2\varphi\xi^2$	2·949	33
Phosphorous acid	$\alpha^2\varphi\xi^3$	3·664	41
Orthophosphoric acid......	$\alpha^2\varphi\xi^4$	4·379	49
Pyrophosphoric acid	$\alpha^3\varphi^2\xi^7$	7·956	89
Metaphosphoric acid	$\alpha\varphi\xi^3$	3·574	40
Protosulphide of phosphorus	$\alpha\varphi^2\theta$	4·201	48
Tersulphide of phosphorus..	$\alpha\varphi^2\theta^3$	7·061	80
Pentasulphide of phosphorus	$\alpha\varphi^2\theta^5$	9·921	112
Terchloride of phosphorus ..	$\alpha^2\varphi\chi^3$	6·145	68·75
Pentachloride of phosphorus	$\alpha^3\varphi\chi^5$	9·319	104·25
Oxychloride of phosphorus..	$\alpha^2\varphi\chi^3\xi$	6·869	76·75
Terbromide of phosphorus ..	$\alpha^2\varphi\beta^3$	12·112	135·5
Pentabromide of phosphorus	$\alpha^3\varphi\beta^5$	19·264	215·5
Oxybromide of phosphorus	$\alpha^2\varphi\beta^3\xi$	12·827	143·5
Bromide of phosphonium ..	$\alpha^3\varphi\beta$	5·140	57·5
Biniodide of phosphorus....	$\alpha^3\varphi^2\omega^4$	25·476	285
Teriodide of phosphorus....	$\alpha^2\varphi\omega^3$	18·413	206
Iodide of phosphonium	$\alpha^3\varphi\omega$	7·240	81
Sulphochloride of phosphorus	$\alpha^2\varphi\chi^3\theta$	7·575	84·75

(10) *Symbol of Arsenic.*—The density of the chloride of arsenic has been determined by **Dumas**, the density of arsenic-vapour by **Mitscherlich**.

Four volumes of the chloride of arsenic are decomposed into 1 volume of arsenic and 6 volumes of chlorine.

Hence, putting $\alpha^m\chi^{m_1}\varrho^{m_2}$ as the symbol of the unit of chloride of arsenic, and $\alpha^n\chi^{n_1}\varrho^{n_2}$ as the symbol of the unit of arsenic, and $\alpha\chi^2$ as the symbol of the unit of chlorine,

$$4\alpha^m\chi^{m_1}\varrho^{m_2}=6\alpha\chi^2+\alpha^n\chi^{n_1}\varrho^{n_2},$$

and

$$(\alpha^m\chi^{m_1}\varrho^{m_2})^4=(\alpha\chi^2)^6\alpha^n\chi^{n_1}\varrho^{n_2};$$

whence

$$4m=6+n,\ \ 4m_1=12+n_1,\ \ 4m_2=n_2.$$

The minimum solution of these equations gives

$$\begin{aligned} m&=2, & n&=2,\\ m_1&=3, & n_1&=0,\\ m_2&=1, & n_2&=4; \end{aligned}$$

and we have, as thus determined,

Symbol of arsenic . . . . $\alpha^2\varrho^4$,
Symbol of terchloride of arsenic . . $\alpha^2\chi^3\varrho$.

Assuming 150 as the density of the vapour of arsenic,

$$2+4w(\varrho)=150,$$
$$w(\varrho)=37.$$

Combinations of the Prime Factors α, ξ, θ, χ, ... and ϱ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ϱ	3·308	37
	Symbol.		
Arsenic	$\alpha^2\varrho^4$	13·408	150
Arsenide of hydrogen......	$\alpha^2\varrho$	3·485	39
Teroxide of arsenic	$\alpha^2\varrho^4\xi^6$	17·699	198
Pentoxide of arsenic	$\alpha\varrho^2\xi^5$	10·279	115
Arsenious acid	$\alpha^2\varrho\xi^3$	5·630	63
Arsenic acid	$\alpha^2\varrho\xi^5$	6·345	71
Bisulphide of arsenic	$\alpha\varrho^2\theta^2$	9·563	107
Tersulphide of arsenic	$\alpha\varrho^2\theta^3$	10·995	123
Pentasulphide of arsenic ..	$\alpha\varrho^2\theta^5$	13·856	155
Terchloride of arsenic	$\alpha^2\varrho\chi^3$	8·111	90·75
Oxychloride of arsenic	$\alpha\varrho\chi\xi$	5·653	63·25
Teriodide of arsenic	$\alpha^2\varrho\omega^3$	20·379	228
Terbromide of arsenic	$\alpha^2\varrho\beta^3$	14·078	157·5

(11) *Symbol of Mercury.*—Assuming 100 as the density of the vapour of mercury, and

135·5 as the density of the vapour of mercuric chloride, 1 volume of mercuric chloride is decomposed into 1 volume of chlorine and 1 volume of mercury.

Hence, putting $\alpha^m\chi^{m_1}\delta^{m_2}$ as the symbol of the unit of mercuric chloride, and $\alpha^n\chi^{n_1}\delta^{n_2}$ as the symbol of the unit of mercury,

$$\alpha^m\chi^{m_1}\delta^{m_2}=\alpha\chi^2+\alpha^n\chi^{n_1}\delta^{n_2},$$

and

$$\alpha^m\chi^{m_1}\delta^{m_2}=\alpha\chi^2\alpha^n\chi^{n_1}\delta^{n_2};$$

whence

$$m=1+n, \quad m_1=2+n_1, \quad m_2=n_2.$$

The minimum solution of these equations gives

$$\begin{aligned} m&=1, & n&=0, \\ m_1&=2, & n_1&=0, \\ m_2&=1, & n_2&=1; \end{aligned}$$

whence we have

Symbol of mercuric chloride . . $\alpha\chi^2\delta$,
Symbol of mercury . . . . δ,

and

$$w(\delta)=100.$$

Combinations of the Prime Factors α, ξ, θ, λ, χ, ... and δ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	δ	8·939	100
	Symbol.		
Mercury	δ	8·939	100
Mercurous oxide	$\delta^2\xi$	18·593	208
Mercuric oxide	$\delta\xi$	9·654	108
Mercurous sulphide	$\delta^2\theta$	19·309	216
Mercuric sulphide	$\delta\theta$	10·369	116
Mercuric sulphite	$\delta\theta\xi^3$	12·514	140
Basic mercuric sulphite	$\delta^2\theta\xi^4$	22·169	248
Mercurous sulphate	$\delta^2\theta\xi^4$	22·169	248
Mercuric sulphate	$\delta\theta\xi^4$	13·230	148
Basic mercuric sulphate (Turpeth's mineral)	$\delta^3\theta\xi^6$	32·539	364
Sulphate and sulphide of mercury	$\delta^3\theta^2\xi^4$	32·539	364
Selenide of mercury	$\delta\lambda$	12·515	140
Mercurous selenite	$\delta^2\lambda\xi^3$	23·600	264
Mercuric selenite	$\delta\lambda\xi^3$	14·661	164
Mercurous chloride	$\alpha\chi^2\delta^2$	21·051	235·5
Mercuric chloride	$\alpha\chi^2\delta$	12·113	135·5
Oxychloride of mercury, 1	$\alpha\chi^2\delta^3\xi^2$	31·421	351·5
Oxychloride of mercury, 2	$\alpha\chi^2\delta^4\xi^3$	41·075	459·5
Oxychloride of mercury, 3	$\alpha\chi^2\delta^5\xi^4$	50·730	567·5
Mercurous chlorate	$\alpha\chi^2\delta^2\xi^6$	25·342	283·5
Mercuric chlorate	$\alpha\chi^2\delta\xi^6$	16·404	183·5
Mercurous perchlorate	$\alpha\chi^2\delta^2\xi^8$	26·772	299·5
Mercuric perchlorate	$\alpha\chi^2\delta\xi^8$	17·834	199·5
Chloride of mercury and sulphur	$\alpha^2\chi^4\delta^2\theta$	25·655	287
Mercurous iodide	$\alpha\omega^2\delta^2$	29·231	327
Intermediate iodide	$\alpha^3\omega^6\delta^4$	69·814	781
Mercuric iodide	$\alpha\omega^2\delta$	20·292	227
Mercurous iodate	$\alpha\omega^2\delta^2\xi^6$	33·521	375
Mercuric iodate	$\alpha\omega^2\delta\xi^6$	24·583	275
Mercurous bromide	$\alpha\beta^2\delta^2$	25·029	280
Mercuric bromide	$\alpha\beta^2\delta$	16·090	180
Trimercuramine	$\alpha\nu^2\delta^3$	28·069	314
Mercurous nitrate	$\alpha\nu^2\delta^2\xi^6$	23·420	262
Mercuric nitrate	$\alpha\nu^2\delta\xi^6$	14·481	162
Nitrate and sulphide of mercury	$\alpha\nu^2\delta^3\theta^2\xi^6$	35·220	394
Nitrate and iodide of mercury	$\alpha\nu\omega\delta\xi^3$	17·386	194·5
Mercuramine	$\alpha^3\nu^2\delta^4\xi^3$	39·332	440
*A	$\alpha^2\nu\chi\delta^2$	20·179	225·75
B	$\alpha^2\nu\chi\delta$	11·240	125·75
C	$\alpha^5\nu^2\chi^2\delta$	13·632	152·5
Mercurous phosphate	$\alpha\phi^2\delta^6\xi^8$	62·128	695
Mercuric phosphate	$\alpha\phi^2\delta^3\xi^8$	35·310	395

---

* A. Formed by the action of ammonia on calomel. B. Formed by the action of ammonia on corrosive sublimate. C. Formed by the action of B on sal-ammoniac.

The preceding Tables comprise a large number of the ascertained combinations of the prime factors to which they relate, and afford sufficient illustration of the method. Hereafter I shall limit myself, in the case of each factor, to a few examples.

With regard to the selection of letters by which the symbols of simple weights may be expressed, it is a mistake to confuse the objects of a symbolic system with those of a "memoria technica," and I am inclined to believe that a purely accidental distribution of letters among the weights to be expressed would be the best. In the selection here made, however, I have not proceeded rigidly upon this principle, a certain reminiscence of the name being retained in the symbol, as for example, the ξ of ὀξύς, the θ of θεῖον, the χ of χλωρός, and the δ of ὑδράργυρος. Facility of writing and reading the symbols is, however, far more important than any aid to memory which can be thus afforded, and these points are to be mainly considered. The unit of hydrogen, which occupies a peculiar position as the "modulus" of the system, is indicated by a special symbol, α. With regard to names, I cannot pretend to be more successful than others. In the confusion which at present prevails on this point it is almost impossible to use a language which shall be universally understood, new names having been frequently and inconsiderately assigned to chemical substances as the expression of some transitory theory, or even individual speculation, rather than to fulfil the main purpose of words, as the common medium for the exchange of ideas. Hence, as in the language of barbarous tribes* and from causes similar to those which there prevail, the same object comes to be denoted by a variety of appellations, and chemists of different schools can hardly understand one another. It is to be hoped that, as the science gradually assumes a more exact form, the use of symbols will enable the chemist to dispense, to a great extent, with any other nomenclature, and afford a satisfactory solution to this difficult problem.

Group 2.—*Symbols of Carbon, Silicon, and Boron.*

(1) *Symbol of Carbon.*—Although the density of the vapour of carbon has never been determined by experiment, we are yet able to construct numerous chemical equations which connect the vapour-density of carbon with known vapour-densities, and in which the number of volumes of carbon-vapour which enters into the chemical equation appears as an indeterminate quantity. From these equations we are able to determine with a high degree of probability, though doubtless only by the aid of hypothesis, the symbols of many gaseous compounds of carbon, the prime factor of carbon, and, within certain limits, the symbol of the element itself.

It is known from experiment that marsh-gas can be decomposed into hydrogen and carbon, and that the number of volumes of hydrogen formed in this decomposition is twice the number of volumes of marsh-gas decomposed.

---

* "Any feature that struck the observing mind as peculiarly characteristic could be made to furnish a new name. In common Sanskrit dictionaries we find five words for land, 11 for light, 15 for cloud, 20 for moon, &c."—MAX MÜLLER, 'Lectures on the Science of Language,' Ed. v. p. 426. It would be easy to find parallel examples in the nomenclature of chemistry.

Hence, putting y as the number of units of marsh-gas thus decomposed, and x as the number of units of the vapour of carbon formed, and putting $\alpha^m\varkappa^{m_1}$ as the symbol of marsh-gas, and $\alpha^n\varkappa^{n_1}$ as the symbol of carbon,

$$y\alpha^m\varkappa^{m_1}=2y\alpha+x\alpha^n\varkappa^{n_1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

whence

$$(\alpha^m\varkappa^{m_1})^y=\alpha^{2y}(\alpha^n\varkappa^{n_1})^x,$$

and

$$\begin{aligned} m\,y&=2\,y+nx,\\ m_1y&=\ n_1x. \end{aligned}$$

Now, whatever be the values of y and x, these equations will admit of a minimum integral solution, provided only that y and x be integral numbers.

This solution is

$$\begin{aligned} m&=2, &\qquad m_1&=x,\\ n&=0, &\qquad n_1&=y. \end{aligned}$$

As determined, therefore, from this equation, we have

Symbol of marsh-gas . . . $\alpha^2\varkappa^x$,
Symbol of carbon . . . . $\varkappa^y$.

Assuming 8 as the density of marsh-gas,

$$2+xw(\varkappa)=8,$$

whence

$$xw(\varkappa)=6\,;$$

and putting W as the density of carbon-vapour,

$$W=\frac{6y}{x},$$

the above equation (1) being thus expressed,

$$y(\alpha^2\varkappa^x)=2y\alpha+x\varkappa^y.$$

We now should proceed to ascertain whether the same symbol, $\varkappa^y$, for carbon will satisfy the conditions afforded by other equations. I will give one or two examples of the process by which this is effected.

It is known from experiment that y_1 volumes of olefiant gas are decomposed into $2y_1$ volumes of hydrogen and x_1 volumes of carbon-vapour. Hence the absolute weight of carbon formed by the decomposition of a unit of olefiant gas is $\frac{x_1}{y_1}$W.

But this weight is determined by experiment, and is equal to twice the weight of carbon formed by the decomposition of a unit of marsh-gas, which weight is equal to $\frac{x}{y}$W. Hence $\frac{x_1}{y_1}=\frac{2x}{y}$; and putting $\alpha^p\varkappa^{p_1}$ as the symbol of olefiant gas, and $\varkappa^y$, as before, as the symbol of carbon,

$$y\alpha^p\varkappa^{p_1}=2y\alpha+2x\varkappa^y,$$

and

$$p=2,\quad p_1=2x,$$

whence we have the symbol of olefiant gas $\alpha^2\varkappa^{2x}$; and the symbol of carbon can be expressed in this equation also as $\varkappa^y$, where y has the value given in equation (1).

Again, by similar reasoning, putting $\alpha^{q}\kappa^{q_1}$, for example, as the symbol of styrol,

$$y\alpha^{q}\kappa^{q_1}=4y\alpha+(\kappa^{y})^{8x},$$

whence

$$q=4, \qquad q_1=8x,$$

and we have as the symbol of styrol $\alpha^4\kappa^{8x}$.

The following are examples of symbols thus determined:—

Marsh-gas	$\alpha^2\kappa^{x}$.
Acetylene	$\alpha\kappa^{2x}$.
Olefiant gas	$\alpha^2\kappa^{2x}$.
Methyl	$\alpha^3\kappa^{2x}$.
Propylene	$\alpha^3\kappa^{3x}$.
Ethyl	$\alpha^5\kappa^{4x}$.
Allyl	$\alpha^5\kappa^{6x}$.
Formic acid	$\alpha\kappa^{x}\xi^2$.
Methylic alcohol	$\alpha^2\kappa^{x}\xi$.
Oxide of ethylene	$\alpha^2\kappa^{2x}\xi$.
Acetic acid	$\alpha^2\kappa^{2x}\xi^2$.
Butylic alcohol	$\alpha^5\kappa^{4x}\xi$.
Benzoic acid	$\alpha^3\kappa^{7x}\xi^2$.
Chloride of methyl	$\alpha^2\chi\kappa^{x}$.
Chloride of ethyl	$\alpha^3\chi\kappa^{2x}$.
Chlorine derivatives of chloride of ethyl, 1	$\alpha^3\chi^2\kappa^{2x}$.
,, ,, ,, ,, 2	$\alpha^3\chi^3\kappa^{2x}$.
,, ,, ,, ,, 3	$\alpha^3\chi^4\kappa^{2x}$.
Chloride of butylene	$\alpha^5\chi^2\kappa^{4x}$.
Chloride of amyl	$\alpha^6\chi\kappa^{5x}$.
Chloride of benzoyl	$\alpha^3\chi\kappa^{7x}\xi$.
Cyanogen	$\alpha\nu^2\kappa^{2x}$.
Cyanide of methyl	$\alpha^2\nu\kappa^{2x}$.
Ethylamine	$\alpha^4\nu\kappa^{2x}$.
Cyanide of butyl	$\alpha^5\nu\kappa^{5x}$.
Cyanide of amyl	$\alpha^6\nu\kappa^{6x}$.

Were we thus to proceed to construct the symbols of the gaseous compounds of carbon with the elements of which the symbols have already been determined, it would be found that in all cases these symbols could be expressed by an integral number of the prime factors α, ξ, θ, λ, χ, ω, ν, ..., and that the index of the factor κ was always of the form mx, m being a positive integer.

The only hypothesis which can be made as to the value of x, which shall be at once necessary and sufficient, is that $x=1$, in which case $w(\kappa)=6$, and W, the density of carbon, $=y\times 6$. This hypothesis is based upon a very large number of observations of the most varied character, and consequently a very high degree of probability is attached to it. For we cannot but believe that if any chemical substance could exist, in the symbol of which the index of κ should not be of the form mx, among the great variety of known substances some one such substance would have been discovered, and that the reason why the weight κ^x is never distributed in the chemical changes with which we are acquainted is that this weight is a simple weight, and that $x=1$.

It is to be observed that the weight to be given to an argument of this kind may become very small, if the observations on which it is founded are few, and made exclusively on one class of substances. Thus, for example, if the course of chemical inquiry had been such as to make us acquainted only with the following substances: olefiant gas, methyl, ethyl, butylene, oxide of ethylene, glycol, alcohol, ether, acetic acid, and other substances of which the symbols can be expressed by the factor κ_1^z, and of which the symbols are $\alpha^2\kappa_1^z$, $\alpha^3\kappa_1^z$, $\alpha^5\kappa_1^{2z}$, $\alpha^4\kappa_1^{2z}$, $\alpha^2\kappa_1^z\xi$, $\alpha^3\kappa_1^z\xi^2$, $\alpha^3\kappa_1^z\xi$, $\alpha^5\kappa_1^{2z}\xi$, $\alpha_1^2\kappa^z\xi^2$, $\alpha^3\kappa_1^{2z}\xi^3$, and the like, where $z=2x$, we should, by similar reasoning, have concluded that the symbols of the compounds of carbon could be expressed by the prime factor κ_1, of which the absolute weight $w(\kappa_1)=12$, and that κ_1 was the symbol of a simple weight, a result which would not have been justified by a more extended experience.

We are able to bring to bear upon the symbol of carbon certain arguments of a very general application, and which are derived from direct experiment. If we compare the chemical equations into which enter the symbols of the units of volume of those elements of which the density can be experimentally determined, it will be perceived that, putting A as the smallest weight of the element which is in any case formed in the decomposition of the unit of any chemical substance, and V as the density of the element, either $A=V$, as in the case of mercury, or $A=\frac{V}{2}$, as in the case of hydrogen, chlorine, iodine, bromine, nitrogen, oxygen, sulphur, selenium, or $A=\frac{V}{4}$, as in the case of phosphorus and arsenic.

The truth of the above observation will be seen on inspecting the following equations, which have already been interpreted.

I. $A=V$. Mercury:—

$$\alpha\chi^2\delta=\alpha\chi^2+\delta.$$

II. $A=\frac{V}{2}$. Hydrogen, chlorine, iodine, bromine, nitrogen, oxygen, sulphur, selenium:—

$$2\alpha\chi=\alpha+\alpha\chi^2,$$

$$2\alpha\omega=\alpha+\alpha\omega^2,$$

$$2\alpha\beta=\alpha+\alpha\beta^2,$$

$$2\alpha\xi=2\alpha+\xi^2,$$

$$2\alpha\theta=2\alpha+\theta^2,$$

$$2\alpha\lambda=2\alpha+\lambda^2,$$

$$2\alpha^2\nu=3\alpha+\alpha\nu^2.$$

III. $A=\frac{V}{4}$. Phosphorus and arsenic:—

$$4\alpha^2\varphi=6\alpha+\alpha^2\varphi^4,$$
$$4\alpha^2\chi^3\varrho=6\alpha\chi^2+\alpha^2\varrho^4.$$

This weight A, which may be regarded as the limit beyond which the chemical division of the weight of unit of the elemental body cannot be effected, is, it will be observed, half the atomic weight of the element on the most recent and approved system. And it is further true, as a matter of observation, that if X be the weight of an elemental body which is formed in the decomposition of the unit of volume of any chemical substance, X is a multiple of A, so that $X=NA$, where N is a positive integer. The relation which this weight holds to the thermal properties of the element will hereafter be pointed out.

From these considerations a certain probability is raised in regard to the value of V, where the value cannot be experimentally determined, in favour of the values $V=A$, $V=2A$, $V=4A$.

The smallest weight of carbon, A, which is formed by the decomposition of the unit of volume of any chemical substance, in regard to which the point can be experimentally ascertained, is that which is formed by the decomposition of the unit of volume of marsh-gas, formic acid, methylic alcohol, and a few other substances.

Now, the equation which asserts the identity of the unit of weight of marsh-gas with the units of hydrogen and carbon into which it is resolved, is

$$y\alpha^2\varkappa^x=2y\alpha+x\varkappa^y,$$

whence

$$A=\frac{x}{y}V.$$

There are, therefore, from these considerations, three hypotheses more probable than others which may be made as to the value $\frac{x}{y}$.

1. $A=V$, $\frac{x}{y}=1$, $x=1$, $y=1$:—

Symbol of carbon . . $\varkappa$,
Symbol of marsh-gas . $\alpha^2\varkappa$,

in which case the equation is of the form

$$\alpha^2\varkappa=2\alpha+\varkappa.$$

2. $A=\frac{V}{2}$, $\frac{x}{y}=\frac{1}{2}$, $x=1$, $y=2$:—

Symbol of carbon . . $\varkappa^2$,
Symbol of marsh-gas . $\alpha^2\varkappa$,

and

$$2\alpha^2\varkappa=4\alpha+\varkappa^2.$$

3. $A=\frac{V}{4}, \frac{x}{y}=\frac{1}{4}, x=1, y=4$:—

Symbol of carbon . . κ^4,
Symbol of marsh-gas . $\alpha^2\kappa$,

and

$$4\alpha^2\kappa=8\alpha+\kappa^4.$$

The symbol of marsh-gas (and therefore the symbols of every other compound of carbon) is the same, whichever hypothesis be preferred; being, so far, independent of the form of the primary equation.

There is no class of symbols, in regard to which the direct evidence of experiment either entirely or partially fails us, as to which we have more positive knowledge than the symbols of those substances of which the vapour-density can be experimentally determined, and which can be finally decomposed into carbon and the gaseous elements. The formulæ of these substances are usually given with unhesitating confidence, and even the vapour-density of carbon is treated as a reality. The evidence, however, on the former point is far more satisfactory than that on the latter; and with our present information, all that can be asserted with any high degree of probability is that the weight of the unit of carbon is a multiple of 6.

As the extreme limit of chemical certainty is marked by the equation

$$2\alpha\xi=2\alpha+\xi^2,$$

so the equation

$$y\alpha^2\kappa=2y\alpha+\kappa^y$$

may serve to indicate another degree in the same scale of chemical probability; the assumption here made being all that is truly required to determine the symbol of marsh-gas, by which the symbols of the other compounds of carbon are implicitly determined.

Between the forms of equation

$$\alpha^2\kappa=2\alpha+\kappa$$

and

$$2\alpha^2\kappa=4\alpha+\kappa^2,$$

we have no adequate means of selection.

Combinations of the Prime Factors α, ξ, ϑ, λ, χ, ω, ... and κ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	κ	0·536	6
	Symbol.		
Carbon*	κ^y	$y \times 0·536$	$y \times 6$
Acetylene	$\alpha\kappa^2$	1·161	13
Marsh-gas	$\alpha^2\kappa$	0·704	8
Olefiant gas	$\alpha^2\kappa^2$	1·251	14
Benzole	$\alpha^3\kappa^6$	3·486	39
Carbonic oxide	$\kappa\xi$	1·251	14
Carbonic acid	$\kappa\xi^2$	1·967	22
Alcohol	$\alpha^3\kappa^2\xi$	2·056	23
Ether	$\alpha^5\kappa^4\xi$	3·308	37
Allylic alcohol	$\alpha^3\kappa^3\xi$	2·592	29
Benzylic alcohol	$\alpha^4\kappa^7\xi$	4·827	54
Glycol	$\alpha^3\kappa^2\xi^2$	2·771	31
Glycerine	$\alpha^4\kappa^3\xi^3$	4·112	46
Anhydrous acetic acid	$\alpha^3\kappa^4\xi^3$	4·559	51
Acetic peroxide	$\alpha^3\kappa^4\xi^4$	5·274	59
Lactic acid	$\alpha^3\kappa^3\xi^3$	4·023	45
Tetrachloride of carbon	$\alpha^2\chi^4\kappa^2$	7·411	83
Chloride of ethylene	$\alpha^3\chi^2\kappa^2$	4·425	49·5
Chloroform	$\alpha^2\chi^3\kappa$	5·341	59·75
Chloride of acetyl	$\alpha^2\chi\kappa^2\xi$	3·509	39·25
Chloracetic acid	$\alpha^2\chi\kappa^2\xi^2$	4·224	47·25
Trichloracetic acid	$\alpha^2\chi^3\kappa^2\xi^2$	7·308	81·75
Chlorocarbonic acid	$\alpha\chi^2\kappa\xi$	4·425	49·5
Iodide of ethyl	$\alpha^3\omega\kappa^2$	6·973	78
Chloriodide of ethylene	$\alpha^3\chi\omega\kappa^2$	8·515	95·25
Cyanogen	$\alpha\nu^2\kappa^2$	2·324	26
Hydrocyanic acid	$\alpha\nu\kappa$	1·207	13·5
Methylamine	$\alpha^3\nu\kappa$	1·386	15·5
Kakodyl	$\alpha^7\varrho^2\kappa^4$	9·386	105
Cyanide of kakodyl	$\alpha^4\varrho\nu\kappa^3$	5·855	65·5
Iodide of phosphotetrethylium	$\alpha^{11}\omega\varphi\kappa^9$	12·247	137
Mercuric ethide	$\alpha^5\kappa^4\delta$	11·532	129

(2) *Symbol of Silicon.*—In the decomposition of chloride of silicon it has been ascertained that the volume of chlorine formed is double the volume of the chloride of silicon decomposed.

Hence, putting $\alpha^m\chi^{m_1}\sigma^{m_2}$ as the symbol of the unit of chloride of silicon, and $\alpha^n\chi^{n_1}\sigma^{n_2}$ as the symbol of the unit of silicon, and z as the number of units of chloride of silicon decomposed, and z_1 as the number of units of silicon formed, we have

$$z\alpha^m\chi^{m_1}\sigma^{m_2}=2z\alpha\chi^2+z_1\alpha^n\chi^{n_1}\sigma^{n_2},$$

---

* y being the number of units of marsh-gas in the equation (1), Sec. VII. Group 2 (1).

and

$$(\alpha^{m}\chi^{m_1}\sigma^{m_2})^{z}=(\alpha\chi^{2})^{2z}(\alpha^{n}\chi^{n_1}\sigma^{n_2})^{z_1};$$

whence

$$zm=2z+z_1n,$$
$$zm_1=4z+z_1n_1,$$
$$zm_2=z_1n_2,$$

which give

$$m=2,\quad n=0,$$
$$m_1=4,\quad n_1=0,$$
$$m_2=z_1,\quad n_2=z,$$

a minimum, whatever be the values of z and z_1, if only z and z_1 be positive and integral.

This gives as the symbol of chloride of silicon $\alpha^{2}\chi^{4}\sigma^{z_1}$, and the symbol of silicon σ^{z}; and assuming 85 as the density of the chloride of silicon,

$$2+4\times17{\cdot}25+z_1w(\sigma)=85,$$

and

$$w(\sigma)=\frac{14}{z_1}.$$

Again, in the decomposition of silicon-ethyl it has been experimentally ascertained that putting z_2 as the number of volumes of silicon-ethyl decomposed, and z_3, z_4, z_5 as the number of volumes of hydrogen, carbon, and silicon respectively formed by its decomposition,

$$\frac{z_3}{z}=10,\quad \frac{z_4}{z_2}=\frac{8x}{y},\quad \text{and}\quad \frac{z_5}{z_2}=\frac{z_1}{z},$$

where $\frac{x}{y}$ is the ratio of the number of volumes of carbon formed to the number of volumes of marsh-gas decomposed, in the equation expressing the result of the decomposition of that substance (Sec. VII. Group 2 (1)), and z and z_1 have the values assigned to them in the previous equation. Hence, putting $\alpha^{m}\chi^{m_1}\sigma^{m_2}$ as the symbol of silicon-ethyl, κ^{y} as the symbol of carbon, and σ^{z} as the symbol of silicon, and substituting the above values for z_2, z_3, z_4, z_5 in the equation

$$z_2\alpha^{m}\kappa^{m_1}\sigma^{m_2}=z_3\alpha+z_4\kappa^{y}+z_5\sigma^{z},$$

we have

$$yz\times\alpha^{m}\kappa^{m_1}\sigma^{m_2}=10yz\times\alpha+8xz\times\kappa^{y}+yz_1\times\sigma^{z},$$

whence

$$(\alpha^{m}\kappa^{m_1}\sigma^{m_2})^{yz}=\alpha^{10yz}(\kappa^{4})^{8xz}(\sigma^{z})^{yz_1}$$

and

$$m=10,\quad m_1=x,\quad m_2=z_1;$$

and we have for the symbol of silicon-ethyl, as determined from experiment, $\alpha^{10}\kappa^{8x}\sigma^{z_1}$, or, putting $x=1$ (Sec. VII. Group 2 (1)), as in the symbols of the other compounds of carbon, $\alpha^{10}\kappa^{8}\sigma^{z_1}$.

Proceeding in a similar manner with the other gaseous compounds of silicon, we have

	Symbol.
Chloride of silicon	$\alpha^2\chi^4\sigma^{z_1}$.
Silicon-ethyl	$\alpha^{10}\kappa^8\sigma^{z_1}$.
Silicate of ethyl	$\alpha^{10}\kappa^8\xi^4\sigma^{z_1}$.
Silicate of amyl	$\alpha^{22}\kappa^{20}\xi^4\sigma^{z_1}$.
Monochlorhydrine of silicate of ethyl . .	$\alpha^8\chi\kappa^6\xi^3\sigma^{z_1}$.

Now there is but one hypothesis which can be made as to the value of z_1, which is at once necessary and sufficient, namely that $z_1=1$. The reasoning here employed is of the same kind as that by which the symbols of the combinations of carbon were determined; but the observations being few, the conclusion is of a less certain character. By a similar argument also to that before used in regard to the value of A, it may be shown that there is great reason to believe that $z=1$, or $=2$, or $=4$. It is not necessary, however, to make any other assumption than that $z=1$, in which case the density of silicon-vapour is a multiple of 14, which is all that can be asserted with probability.

Putting $z_1=1$, we have the following symbols:—

Combinations of the Prime Factors α, ξ, θ, χ, ... and σ.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	σ	1·251	14
	Symbol.		
Silicon	σ^z	$z\times 1·251$	$z\times 14$
Silica	$\sigma\xi^2$	2·682	30
Monohydrated silicic acid	$\alpha\sigma\xi^3$	3·486	39
Sulphide of silicon	$\sigma\theta^2$	4·112	46
Chloride of silicon	$\alpha^2\chi^4\sigma$	7·598	85
Bromide of silicon	$\alpha^2\beta^4\sigma$	15·554	174
Silicon-ethyl	$\alpha^{10}\kappa^8\sigma$	6·436	72
Silicate of ethyl	$\alpha^{10}\kappa^8\xi^4\sigma$	9·297	104
Silicate of amyl	$\alpha^{22}\kappa^{10}\xi^4\sigma$	11·442	128
Monochlorhydrin of silicate of ethyl	$\alpha^8\chi\kappa^6\xi^3\sigma$	8·872	99·25

(3) *Symbol of Boron.*—In the decomposition of the chloride of boron into its elements, one volume of that substance is decomposed with the formation of $1\frac{1}{2}$ volume of chlorine. Hence, if y_1 be the smallest integral number of units of the chloride of boron decomposed, and y_2 the number of units of boron formed in the decomposition, $\frac{y_1}{y_2}=\frac{2}{3}$; and putting $\alpha^m\chi^{m_1}\beta_1^{m_2}$ as the symbol of the terchloride of boron, and $\alpha^n\chi^{n_1}\beta_1^{n_2}$ as the symbol of boron,

$$2y_1\alpha^m\chi^{m_1}\beta_1^{m_2}=3y_1\alpha\chi^2+y_2\alpha^n\chi^{n_1}\beta_1^{n_2};$$

whence

$$(\alpha^m\chi^{m_1}\beta_1^{m_2})^{2y_1}=(\alpha\chi^2)^{3y_1}(\alpha^n\chi^{n_1}\beta_1^{n_2})^{y_2},$$

and

$$2y_1m=3y_1+y_2n,$$
$$2y_1m_1=6y_1+y_2n_1,$$
$$2y_1m_2=y_2n_2.$$

From the first of these equations it appears (since y_2 and y_1 have no common measure) that y_2 cannot be an even number, if the equation is to admit of an integral solution. Making this assumption, we have, putting $y_2=1+2z$,

$$m=2+z, \quad n=y_1,$$
$$m_1=3, \quad n_1=0,$$
$$m_2=1+2z, \quad n_2=2y_1,$$

a minimum, which give

Symbol of chloride of boron .	$\alpha^{2+z}\chi^3\beta_1^{1+2z}$,
Symbol of boron	$\alpha^{y_1}\beta_1^{2y_1}$.

Also, since 5·5 parts of boron are formed by the decomposition of 1 volume of chloride of boron of the density 58·75, putting W as the density of boron-vapour,

$$\frac{y_2\mathrm{W}}{2y_1}=\frac{y_2(1+2w(\beta_1))}{2}=5{\cdot}5,$$

and putting $y_2=1+2z$,

$$w(\beta_1)=\frac{5-z}{1+2z}.$$

Again, putting $\alpha^m\varkappa^{m_1}\beta_1^{m_2}$ as the symbol of boric methide, and (as before) $\frac{x}{y}$ as the number of volumes of carbon formed by the decomposition of one volume of marsh-gas, and giving to y_1 and y_2 the same values as in the last equation, it is known from experiment that

$$2yy_1\alpha^m\varkappa^{m_1}\beta_1^{m_2}=9yy_1\alpha+6xy_1\varkappa^y+yy_2\alpha^{y_1}\beta_1^{2y_1};$$

whence

$$2m=9+y_2,$$
$$2m_1=6x,$$
$$m_2=y_2;$$

and putting $y_2=1+2z$, and $x=1$,

$$m=5+z,$$
$$m_1=3,$$
$$m_2=1+2z,$$

and we have for the symbol of boric methide $\alpha^{5+z}\varkappa^3\beta_1^{1+2z}$.

Proceeding in a similar manner with the other gaseous combinations of boron, we arrive at the following symbols:—

	Symbol.
Boron	$\alpha^{y_1}\beta_1^{2y_1}$.
Chloride of boron . . .	$\alpha^{2+z}\beta_1^{1+2z}\chi^3$.
Boric methide	$\alpha^{5+z}\beta_1^{1+2z}\kappa^3$.
Boric ethide	$\alpha^{8+z}\beta_1^{1+2z}\kappa^6$.
Trimethylic borate . . .	$\alpha^{5+z}\beta_1^{1+2z}\kappa^3\xi^3$.
Triethylic borate . . .	$\alpha^{8+z}\beta_1^{1+2z}\kappa^6\xi^3$.
Triamylic borate . . .	$\alpha^{17+z}\beta_1^{1+2z}\kappa^{15}\xi^3$.

By similar reasoning to that employed in the case of silicon, we are led to assume in this system of symbols $z=0$, which results in the system given in the following Table.

Combinations of the Prime Factors α, ξ, θ, χ, ... and β_1.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	β_1	0·447	5
	Symbol.		
Boron	$\alpha^y\beta_1^{2y}$	$y\times0{\cdot}983$	$y\times11$
Teroxide of boron	$\alpha\beta_1^2\xi^3$	3·129	35
Boracic acid	$\alpha^2\beta_1\xi^3$	2·771	31
Terchloride of boron	$\alpha^2\beta_1\chi^3$	5·252	58·75
Nitride of boron	$\alpha\beta_1\nu$	1·117	12·5
Boric methide	$\alpha^5\beta_1\kappa^3$	2·503	28
Trimethylic borate	$\alpha^5\beta_1\kappa^3\xi^3$	4·648	52
Triethylic borate	$\alpha^8\beta_1\kappa^6\xi^3$	6·534	73
Triamylic borate	$\alpha^{17}\beta_1\kappa^{15}\xi^3$	12·157	136
Boric ethide	$\alpha^8\beta_1\kappa^6$	4·380	49

If we proceed to determine the most probable symbol of boron by aid of the hypothesis $A=V$, or $A=\frac{V}{2}$, or $A=\frac{V}{4}$ (Sec. VII. Group 2 (1)), we have in case (i) $A=V$, $\frac{y_2}{2y_1}=1$, which admits of no integral solution, y_2 being odd and y_1 prime to y_2; in case (ii) $A=\frac{V}{2}$, $\frac{y_2}{2y_1}=\frac{1}{2}$, and $y_2=1$, $y_1=1$; in case (iii) $A=\frac{V}{4}$, $\frac{y_2}{2y_1}=\frac{1}{4}$, and $y_2=1$, $y_1=2$. Hence the more probable symbols for boron (from these considerations) are $\alpha\beta_1^2$ and $\alpha^2\beta_1^4$, between which we cannot decide.

The symbols which have been assigned to the gaseous compounds of the preceding elements, silicon and boron, are to be regarded as the symbolic expression of the most probable hypothesis as to their chemical constitution, which is consistent with the known facts of gaseous combination. What weight, we may ask, is to be attached to such conclusions? Now, it has already been remarked that the weight to be given to such hypotheses primarily depends upon the number of cases to which they are applicable. But in the case of these elements we are acquainted only with a very limited number of gaseous compounds; and it must be admitted that, regarded exclusively from this point of view, but little value could be attached to any inference at which we thus arrive; for the conclusions drawn from six or seven instances, accidentally selected, would not improbably be negatived by a more extended experience. But our judgment is in truth based upon considerations of a far more complex character; and it would be unreasonable not to extend our view to the probabilities derived from other sources of the inferences to which the various hypotheses lead, and which often enable us to select among them.

For example, in the symbol of the chloride of boron, $\alpha^{2+z}\chi^3\beta_1^{1+2z}$, the value of z is necessarily limited only by the condition $w(\beta_1)=\frac{5-z}{1+2z}$, whence z is less than 5. But if we proceed to assign to z the different values 0, 1, 2, 3, 4, it will be found that on the first hypothesis, $z=0$, the combinations of the prime factor β_1 form a system strictly similar in the laws of their construction to the system of the combinations of the prime factors ν, φ, and ϱ; whereas on the other hypotheses they are analogous to no existing system whatever.

Thus, putting $z=0$, we have the following parallel systems, limiting our view for the moment to the gaseous compounds of boron.

	$z=0.$		
Boron	$(\alpha\beta_1^2)^2$	Nitrogen	$\alpha\nu^2$
Chloride of boron	$\alpha^2\beta_1\chi^3$	Chloride of nitrogen	$\alpha^2\nu\chi^3$
Boric methide	$\alpha^5\beta_1\varkappa^3$	Methylamine	$\alpha^5\nu\varkappa^3$
Boric ethide	$\alpha^8\beta_1\varkappa^6$	Ethylamine	$\alpha^8\nu\varkappa^6$
Triethylic borate	$\alpha^8\beta_1\varkappa^6\xi^3$		
Phosphorus	$(\alpha\varphi^2)^2$	Arsenic	$(\alpha\varrho^2)^2$
Chloride of phosphorus	$\alpha^2\varphi\chi^3$	Chloride of arsenic	$\alpha^2\varrho\chi^3$
Trimethyl-phosphine	$\alpha^5\varphi\varkappa^3$	Trimethyl-arsine	$\alpha^5\varrho\varkappa^3$
Triethyl-phosphine	$\alpha^8\varphi\varkappa^6$	Triethyl-arsine	$\alpha^8\varrho\varkappa^6$
Phosphite of ethyl	$\alpha^8\varphi\varkappa^6\xi^3$		

If we put $z=1, 2, 3, 4$, the system of the gaseous compounds of boron appears with the following symbols:—

	$z=1.$	$z=2.$	$z=3.$	$z=4.$
Chloride of boron	$\alpha^3\beta^3\chi^3$	$\alpha^4\beta^5\chi^3$	$\alpha^5\beta^7\chi^3$	$\alpha^6\beta^9\chi^3$
Boric methide	$\alpha^6\beta^3\varkappa^3$	$\alpha^7\beta^5\varkappa^3$	$\alpha^8\beta^7\varkappa^3$	$\alpha^9\beta^9\varkappa^3$
Boric ethide	$\alpha^9\beta^3\varkappa^6$	$\alpha^{10}\beta^5\varkappa^6$	$\alpha^{11}\beta^7\varkappa^6$	$\alpha^{12}\beta^9\varkappa^6$
Triethylic borate	$\alpha^9\beta^3\varkappa^6\xi^3$	$\alpha^{10}\beta^5\varkappa^6\xi^3$	$\alpha^{11}\beta^7\varkappa^6\xi^3$	$\alpha^{12}\beta^9\varkappa^6\xi^3$

to which no parallel can be found among known and existing systems.

This coincidence cannot be regarded as of an accidental character. It is doubtless the result of the profound analogy of chemical properties by which this group of elements is connected, and which is revealed to us in the similarity of the symbolic forms of their combinations.

Group 3.—*Symbols of Antimony, Bismuth, Tin, Zinc, Cadmium, and Silver.*

It is evident that if some property of matter were discovered which admitted of accurate estimation, and which should vary with the gaseous density according to a known law, we should be able to infer the density from this property. Now in the numbers which represent the relative specific heats of chemical substances certain remarkable relations have been observed, which render it probable that general laws of this kind will hereafter be discovered, connecting the gaseous density of chemical substances with their specific heat, and which will afford a more solid foundation than we at present possess for the construction of a complete system of theoretical chemistry.

The law of Dulong and Petit is the most important of these numerical relations which has been as yet ascertained. This law may be regarded as an experimental truth, and thus stated:

If $A, A_1, A_2, \ldots . A_n$ be the smallest weights of the elemental bodies formed by the decomposition of the unit of any chemical substance, and if $h, h_1, h_2, \ldots h_n$ be the specific heats of these elements, either in the liquid or solid condition, then

$$hA = h_1A_1 = h_2A_2 = \ldots . h_nA_n.$$

In the following Table the value of the ratio $\frac{hA}{h_1A_1}$ is given in the case of those elements of which the symbols have been considered, and of which the specific heats have been experimentally determined, with the exception of the elements carbon, boron, and silicon, which do not appear to satisfy the condition. But these substances affect several allotropic forms, and have more than one specific heat; and it is not improbable that some variety of these elements may yet be discovered which shall conform to the law.

In the last column h_mA_m is assumed as the mean of the values given in the preceding column, namely, 3·289.

	A.	h.	hA.	$\frac{hA}{h_mA_m}$.
Sulphur	16	0·2026	3·241	0·985
Selenium	40	0·0837	3·348	1·018
Iodine	63·5	0·0541	3·436	1·045
Bromine	40	0·0843	3·372	1·025
Phosphorus	15·5	0·2120	3·285	0·999
Arsenic	37·5	0·0814	3·052	0·928

Hence if the specific heat, h, of an element be known, we are able, from the equation $A = \frac{h_mA_m}{h} = \frac{3·289}{h}$, to calculate the value of A. The reasons have already been given which lead us to assume, with a certain probability, that W being the density of the element, $A = W$, or $= \frac{W}{2}$, or $= \frac{W}{4}$. Whence, if A be known, W is determined within certain limits.

Symbol of Antimony.—In the decomposition of the terchloride of antimony into its elements, if y be the number of units of the terchloride of antimony decomposed, and y_1 the number of units of chlorine formed in the decomposition,

$$\frac{y}{y_1}=\frac{2}{3};$$

whence, if y_2 be the greatest common measure of y and y_1, $y=2y_2$, and $y_1=3y_2$; and putting y_3 as the number of units of antimony formed, W as the density of antimony, V as the density of chlorine, and V_1 as the density of terchloride of antimony,

$$y_3W=y_2(2V_1-3V),$$

and since $V=35{\cdot}5$, and $V_1=114{\cdot}25$, as experimentally determined,

$$y_3W=y_2 122.$$

Now the specific heat of antimony, as determined by Regnault, is 0·05077; whence, putting $A=\frac{h_m A_m}{h}$,

$$A=\frac{3{\cdot}289}{0{\cdot}05077}=64{\cdot}8;$$

and since $2\times 64{\cdot}4=128{\cdot}8$ may be regarded as approximately equal to 122, we may assume, within the limits of error, that in the above decomposition

$$y_3W=2y_2A.$$

Now three hypotheses may, as has been shown, be made as to the probable value of W.

1. $W=A$, in which case $y_3=2y_2$.
2. $W=2A$, in which case $y_3=y_2$.
3. $W=4A$, in which case $2y_3=y_2$.

Further, putting $\alpha^m\chi^{m_1}\sigma_1^{m_2}$ as the symbol of the terchloride of antimony, $\alpha\chi^2$ as the symbol of chlorine, and $\alpha^n\chi^{n_1}\sigma_1^{n_2}$ as the symbol of antimony, we have

$$2y_2(\alpha^m\chi^{m_1}\sigma_1^{m_2})=3y_2\alpha\chi^2+y_3\alpha^n\chi^{n_1}\sigma_1^{n_2},$$

$$(\alpha^m\chi^{m_1}\sigma_1^{m_2})^{2y_2}=(\alpha\chi^2)^{3y_2}(\alpha^n\chi^{n_1}\sigma_1^{n_2})^{y_3};$$

whence

$$2m\,y_2=3y_2+ny_3,$$
$$2m_1y_2=6y_2+n_1y_3,$$
$$2m_2y_2=n_2y_3.$$

1. Now on the first hypothesis $y_3=2y_2$, which is incompatible with any solution in whole numbers of the first of these equations, which then becomes

$$2m=3+2n:$$

this hypothesis is therefore to be rejected.

2. In the second case $y_3=y_2$, and we have

$$2m=3+n,$$
$$2m_1=6+n_1,$$
$$2m_2=n_2,$$

the minimum integral solutions of which equations give

$$m=2,\quad n=1,$$
$$m_1=3,\quad n_1=0,$$
$$m_2=1,\quad n_2=2,$$

and we have as the

Symbol of terchloride of antimony . $\alpha^2\chi^3\sigma_1$,
Symbol of antimony . . . . $\alpha\sigma_1^2$.

3. On the third hypothesis $2y_3=y_2$, and

$$4m=6+n,$$
$$4m_1=12+n_1,$$
$$4m_2=n_2,$$

and

$$m=2,\quad n=2,$$
$$m_1=3,\quad n_1=0,$$
$$m_2=1,\quad n_2=4,$$

a minimum, and the symbol of the terchloride is, as before, $\alpha^2\chi^3\sigma_1$, and the symbol of antimony $\alpha^2\sigma_1^4$, the equations on the two hypotheses being thus expressed:

Hypothesis II. . . . . . $2\alpha^2\chi^3\sigma_1=3\alpha\chi^2+\alpha\sigma_1^2$.
Hypothesis III. . . . . . $4\alpha^2\chi^3\sigma_1=6\alpha\chi^2+\alpha^2\sigma_1^4$.

The symbol of the terchloride, and of all other compounds of antimony, is the same on either view.

Combinations of the Prime Factors α, ξ, θ, χ, ... and σ_1.

Name.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	σ_1	5·408	60·5
	Symbol.		
Antimony, Hypothesis 1 ..	$\alpha\sigma_1^2$	10·905	122
Antimony, Hypothesis 2 ..	$\alpha^2\sigma_1^4$	21·810	244
Teroxide of antimony	$\alpha\sigma_1^2\xi^3$	13·051	146
Tetroxide of antimony	$\alpha\sigma_1^2\xi^4$	13·767	154
Pentoxide of antimony	$\alpha\sigma_1^2\xi^5$	14·482	162
Tersulphide of antimony ..	$\alpha\sigma_1^2\theta^3$	15·198	170
Pentasulphide of antimony	$\alpha\sigma_1^2\theta^5$	18·057	202
Terchloride of antimony....	$\alpha^2\sigma_1\chi^3$	10·213	114·25
Pentachloride of antimony..	$\alpha^3\sigma_1\chi^5$	133·86	149·75
Oxychloride of antimony ..	$\alpha\sigma_1\chi\xi$	7·755	86·75

Symbol of Bismuth.—We are able to make precisely similar statements as to the relation which subsists between the densities of the terchloride of bismuth and its elements, chlorine and bismuth, to those which have been made respecting terchloride of antimony; and putting W as the density of bismuth, V the density of chlorine, and V_1 the density of terchloride of bismuth, we have, as before,

$$y_3 W = y_2(2V_1 - 3V);$$

and putting $V=35{\cdot}5$ and $V_1=157{\cdot}25$,

$$y_3 W = y_2 \times 208.$$

Now, the specific heat of bismuth, h, $=0{\cdot}03084$, and putting $A=\frac{3{\cdot}289}{0{\cdot}03084}$,

$$A=106{\cdot}6.$$

We may hence assume that $y_3 W = 2y_2 A$, and, as before, putting

$$\begin{aligned} &1.\ W=\ A, && y_3=2y_2; \\ &2.\ W=2A, && y_3=\ y_2; \\ &3.\ W=4A, && 2y_3=\ y_2; \end{aligned}$$

and by precisely similar reasoning to that in the last example, putting $\alpha^m\chi^{m_1}\beta_2^{m_2}$ as the symbol of terchloride of bismuth, and $\alpha^n\chi^{n_1}\beta_2^{n_2}$ as the symbol of bismuth, from the equation

$$(\alpha^m\chi^{m_1}\beta_2^{m_2})^{2y_2}=(\alpha\chi^2)^{3y_2}(\alpha^n\chi^{n_1}\beta_2^{n_2})^{y_3}$$

we arrive at the following symbols, rejecting, for the same reason as in the case of antimony, the first hypothesis.

On the second hypothesis, $W=2A$,

Symbol of bismuth $\alpha\beta_2^2$,
Symbol of terchloride of bismuth $\alpha^2\chi^3\beta_2$.

On the third hypothesis, $W=4A$,

Symbol of bismuth $\alpha\beta_2^4$,
Symbol of terchloride of bismuth $\alpha^2\chi^3\beta_2$.

We have hence the following system:—

Combinations of the Prime Factors α, ξ, θ, χ, ... and β_2.

Name.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	β_2	9·252	103·5
	Symbol.		
Bismuth, Hypothesis 1	$\alpha\beta_2{}^2$	18·594	208
Bismuth, Hypothesis 2	$\alpha^2\beta_2{}^4$	37·188	416
Teroxide of bismuth	$\alpha\beta_2{}^2\xi^3$	20·739	232
Pentoxide of bismuth	$\alpha\beta_2{}^2\xi^5$	22·169	248
Hydrate of bismuth	$\alpha\beta_2\xi^2$	10·772	120·5
Bismuthic acid	$\alpha\beta_2{}^2\xi^3$	20·739	232
Bisulphide of bismuth	$\alpha\beta_2{}^2\theta^2$	21·454	240
Tersulphide of bismuth	$\alpha\beta_2{}^2\theta^3$	22·884	256
Terchloride of bismuth	$\alpha^2\beta_2\chi^3$	13·967	156·25
Oxychloride of bismuth	$\alpha\beta_2\chi\xi$	11·598	129·75
Triethyl bismuth	$\alpha^8{}_2\varkappa^6$	13·185	147·5
Chloride of protethyl bismuth	$\alpha^4\beta_2\chi^2\varkappa^2$	13·767	154

Symbol of Tin.—In the decomposition of the gaseous chloride of tin into tin and chlorine, the volume of chlorine formed is double the volume of the chloride decomposed. Hence, putting y_1 as the number of units of stannic chloride decomposed, and $\alpha^m\chi^{m_1}\kappa_1^{m_2}$. $\alpha^n\chi^{n_1}\kappa_1^{n_2}$ as the symbols, respectively, of stannic chloride and of tin,

$$y_1\alpha^m\chi^{m_1}\kappa_1^{m_2}=2y_1\alpha\chi^2+y_2\alpha^n\chi^{n_1}\kappa_1^{n_2}$$

and

$$(\alpha^m\chi^{m_1}\kappa_1^{m_2})^{y_1}=(\alpha\chi^2)^{2y_1}(\alpha^n\chi^{n_1}\kappa_1^{n_2})^{y_2},$$

whence

$$y_1m= 2y_1+y_2n,$$
$$y_1m_1=4y_1+y_2n_1,$$
$$y_1m_2=y_2n_2.$$

In all cases

$$m=2,\quad n=0,$$
$$m_1=4,\quad n_1=0,$$
$$m_2=y_2,\quad n_2=y_1,$$

a minimum, and we hence have, as determined from the above equation,

Symbol of tin $\kappa_1^{y_1}$,
Symbol of bichloride of tin $\alpha^2\chi^4\kappa_1^{y_2}$;

and, assuming 130 as the density of bichloride of tin,

$$2w(\alpha)+4w(\chi)+y_2\kappa_1=130;$$

whence

$$y_2w(\kappa_1)=59,$$

and

$$\mathrm{W}=y_1w(\kappa_1)=\frac{y_1}{y_2}59.$$

Now, proceeding to construct the symbols of the other known gaseous compounds of tin by processes precisely similar to those of which sufficient examples have already been given in the case of the elements silicon and boron, and which it is unnecessary here to repeat, we arrive at the following symbols:—

	Symbol.
Bichloride of tin	$\alpha^2\chi^4\kappa_1^{y_2}$.
Chloride of stannic dimethyl . .	$\alpha^4\chi^2\kappa^2\kappa_1^{y_2}$.
Chloride of stannic diethyl . . .	$\alpha^6\chi^2\kappa^4\kappa_1^{y_2}$.
Bromide of stannic diethyl . . .	$\alpha^6\beta^2\kappa^4\kappa_1^{y_2}$.
Iodide of stannic trimethyl . . .	$\alpha^5\omega\kappa^3\kappa_1^{y_2}$.
Chloride of stannic triethyl . .	$\alpha^8\chi\kappa^6\kappa_1^{y_2}$.
Bromide of stannic triethyl . .	$\alpha^8\beta\kappa^6\kappa_1^{y_2}$.
Stannic dimethyl-diethyl . . .	$\alpha^8\kappa^6\kappa_1^{y_2}$.
Stannic tetrethyl	$\alpha^{10}\kappa^8\kappa_1^{y_2}$.

As in the corresponding cases which have already been discussed, there is but one hypothesis which can be made as to the value of y_2, which is at once necessary and sufficient, namely that $y_2=1$, which gives $\alpha^2\chi^4\kappa_1$ as the symbol of bichloride of tin.

Now the specific heat of tin is 0·05623. Hence $A=\frac{3\cdot289}{0\cdot05623}=58\cdot5$; and it is known from experiment that $\frac{y_2}{y_1}W=59$. It may therefore be assumed that $\frac{y_2}{y_1}W=A$.

Hence (1) If $A=W$, $\frac{y_2}{y_1}=1$, and $y_2=1$, $y_1=1$.

(2) If $A=\frac{W}{2}$, $\frac{y_2}{y_1}=\frac{1}{2}$, and $y_2=1$, $y_1=2$.

(3) If $A=\frac{W}{4}$, $\frac{y_2}{y_1}=\frac{1}{4}$, and $y_2=1$, $y_1=4$.

Hence it appears that from these considerations also (whichever hypothesis be preferred) $y_2=1$, and the symbol of bichloride of tin is $\alpha^2\chi^4\varkappa_1$. The symbol of tin is, from these data, either $\varkappa_1$, $\varkappa_1^2$, or $\varkappa_1^4$, between which values we have no means of selecting.

Combinations of the Prime Factors α, ξ, θ, χ, ... and $\varkappa_1$.

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	$\varkappa_1$	5·274	59
	Symbol.		
Tin. Hypothesis 1	$\varkappa_1$	5·274	59
Tin. Hypothesis 2	$\varkappa_1^2$	10·548	118
Tin. Hypothesis 3	$\varkappa_1^4$	21·096	236
Protoxide of tin	$\varkappa_1\xi$	5·989	67
Binoxide of tin	$\varkappa_1\xi^2$	6·704	75
Hydrated stannic acid	$\alpha\varkappa_1\xi^3$	7·509	84
Protosulphide of tin	$\varkappa_1\theta$	6·704	75
Bisulphide of tin	$\varkappa_1\theta^2$	8·135	91
Bichloride of tin	$\alpha\chi^2\varkappa_1$	8·448	94·5
Tetrachloride of tin	$\alpha^2\chi^4\varkappa_1$	11·621	130
Chloride of stannic dimethyl	$\alpha^4\chi^2\varkappa^2\varkappa_1$	9·788	109·5
Chloride of stannic diethyl	$\alpha^6\chi^2\varkappa^4\varkappa_1$	11·040	123·5
Bromide of stannic diethyl	$\alpha^6\beta^2\varkappa^4\varkappa_1$	15·018	168
Iodide of stannic trimethyl	$\alpha^5\omega\varkappa^3\varkappa_1$	12·962	145
Chloride of stannic triethyl	$\alpha^8\chi\varkappa^6\varkappa_1$	10·749	120·25
Bromide of stannic triethyl	$\alpha^8\beta\varkappa^6\varkappa_1$	12·738	142·5
Stannic tetrethyl	$\alpha^{10}\varkappa^8\varkappa_1$	10·459	117
Stannic dimethyl-diethyl	$\alpha^8\varkappa^6\varkappa_1$	9·207	103

Symbol of Zinc.—It is known from experiment that one volume of zinc-ethyl, of which the density is 61·75, can be decomposed into 5 volumes of hydrogen, 24 parts by weight of carbon, and 32·5 parts by weight of zinc.

Now, since 6 parts by weight of carbon are formed by the decomposition of one volume of marsh-gas, putting y_1 as the number of volumes of zinc-ethyl decomposed, and y_2 as the number of volumes of vapour of carbon formed in this decomposition,

$$\frac{y_2}{y_1}=4\frac{x}{y},$$

where x and y have the values previously assigned to them (Sec. VII. Group 2 (1)), and assuming $x=1$,

$$\frac{y_2}{y_1}=\frac{4}{y};$$

whence, putting y_3 as the number of volumes of zinc formed, $\alpha^m\kappa^{m_1}\zeta^{m_2}$ as the symbol of zinc-ethyl, $\alpha^n\kappa^{n_1}\zeta^{n_2}$ as the symbol of zinc, α as the symbol of hydrogen, and κ^y as the symbol of carbon,

$$yy_1(\alpha^m\kappa^{m_1}\zeta^{m_2})=5yy_1\alpha+4y_1\kappa^y+yy_3\alpha^n\kappa^{n_1}\zeta^{n_2},$$

and

$$(\alpha^m\kappa^{m_1}\zeta^{m_2})^{yy_1}=\alpha^{5yy_1}(\kappa^y)^{4y_1}(\alpha^n\kappa^{n_1}\zeta^{n_2})^{yy_3};$$

whence

$$\begin{aligned}y_1m&=5y_1+y_3n,\\ y_1m_1&=4y_1+y_3n_1,\\ y_1m_2&=\phantom{4y_1+{}}y_3n_2,\end{aligned}$$

which equations have for all integral values of y_1 and y_2 the minimum solutions,

$$\begin{aligned}m&=5, &\qquad n&=0,\\ m_1&=4, &\qquad n_1&=0,\\ m_2&=y_3, &\qquad n_2&=y_1,\end{aligned}$$

which give the following expressions for the symbols,

Zinc-ethyl . . . $\alpha^5\kappa^4\zeta^{y_3}$.
Zinc . . . . . ζ^{y_1}.

In a similar manner we arrive at $\alpha^3\kappa^2\zeta^{y_3}$ as the symbol of zinc-methyl.

These are the only gaseous compounds of zinc known.

The specific heat of zinc is 0·0955. Hence it may be assumed that

$$A=\frac{3{\cdot}289}{0{\cdot}0955}=34{\cdot}4.$$

Now from the above equtions

$$\frac{y_3}{y_1}W=32{\cdot}75,$$

W being the density of zinc in the gaseous condition, and approximately

$$\frac{y_3}{y_1}W=A.$$

(1) If $A=W$, $y_3=1$, and $y_1=1$.

(2) If $A=\frac{W}{2}$, $y_3=1$, and $y_1=2$,

(3) If $A=\frac{W}{4}$, $y_3=1$, and $y_1=4$.

On each hypothesis the value of y_3 is the same. Hence we have—

Name of substance.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ζ	2·905	32·5
	Symbol.		
Zinc. Hypothesis 1	ζ	2·905	32·5
Zinc. Hypothesis 2	ζ^2	5·811	65
Zinc. Hypothesis 3	ζ^4	11·621	130
Oxide of zinc	$\zeta\xi$	3·620	40·5
Hydrated oxide of zinc	$\alpha\zeta\xi^2$	4·425	49·5
Sulphide " "	$\zeta\theta$	4·335	48·5
Sulphate " "	$\zeta\theta\xi^4$	7·196	80·5
Hyposulphite " "	$\zeta\theta^2\xi^3$	7·911	88·5
Chloride " "	$\alpha\chi^2\zeta$	6·079	68
Carbonate " "	$\zeta\varkappa\xi^3$	5·587	62·5
Zinc-methyl	$\alpha^3\varkappa^2\zeta$	4·246	47·5
Zinc-ethyl	$\alpha^5\varkappa^4\zeta$	5·498	61·5
Zinc-amide	$\alpha^3\nu^2\zeta$	4·157	46·5

Symbol of Cadmium.—The density of the vapour of cadmium, as ascertained by DEVILLE and TROOST, is 56·7 on the hydrogen scale, and in the decomposition of the chloride of cadmium equal volumes of chlorine and cadmium are formed.

Hence putting

$\alpha^m\chi^{m_1}\varkappa_2^{m_2}$ as the symbol of chloride of cadmium,
$\alpha^n\chi^{n_1}\varkappa_2^{n_2}$ as the symbol of cadmium,
$\alpha\chi^2$ as the symbol of chlorine,

$$y_1\alpha^m\chi^{m_1}\varkappa_2^{m_2}=y_2\alpha\chi^2+y_2\alpha^n\chi^{n_1}\varkappa_2^{n_2},$$

and

$$(\alpha^m\chi^{m_1}\varkappa_2^{m_2})^{y_1}=(\alpha\chi^2)^{y_2}(\alpha^n\chi^{n_1}\varkappa_2^{n_2})^{y_2},$$

whence

$$y_1m = y_2+y_2n,$$
$$y_1m_1=2y_2+y_2n_1,$$
$$y_1m_2= y_2n_2.$$

Now the specific heat of cadmium is 0·05669, whence the calculated value of A $\left(\text{putting } A=\frac{3·289}{0·05669}\right)$ is 58, and $W=A$.

Hence, assuming in conformity with the principle previously laid down, that $\frac{y_2W}{y_1}=XA$, where X is a positive integer, since $W=A$, and y_1 and y_2 have no common measure, $y_1=1$, and the above equations become

$$m = y_2+y_2n,$$
$$m_1=2y_2+y_2n_1,$$
$$m_2= y_2n_2,$$

which in all cases admit of the minimum solutions,

$$\begin{aligned} m &= y_2, & n &= 0, \\ m_1 &= 2y_2, & n_1 &= 0, \\ m_2 &= y_2, & n_2 &= 1, \end{aligned}$$

and we have

Symbol of chloride of cadmium . . $(\alpha\chi^2\varkappa_2)^{y_2}$,
Symbol of cadmium . . . . $\varkappa_2$.

Or, assuming as the most probable hypothesis (in default of further information) that $y_2=1$, we have

Symbol of chloride of cadmium . . $\alpha\chi^2\varkappa_2$.

We hence arrive at the following symbols:—

Combinations of the Prime Factors α, ξ, θ, χ, ... and $\varkappa_2$.

Name.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	$\varkappa_2$	5·006	56
	Symbol.		
Cadmium	$\varkappa_2$	5·006	56
Oxide of cadmium	$\varkappa_2\xi$	5·721	64
Sulphide of cadmium	$\varkappa_2\theta$	6·436	72
Sulphate of cadmium	$\varkappa_2\theta\xi^4$	9·297	104
Chloride of cadmium	$\alpha\chi^2\varkappa_2$	8·179	91·5
Carbonate of cadmium	$\varkappa_2\varkappa\xi^3$	7·688	86

Symbol of Silver.—Lastly, I will give one example of a class of symbols in regard to which we have even less positive knowledge, and are thrown almost exclusively upon hypothesis.

The specific heat of silver is 0·05701, whence the calculated value of A $\left(\text{putting } A=\frac{3\cdot289}{0\cdot05701}\right)$ is 57·6.

Now the percentage composition of chloride of silver is

Silver . . . . 75·26
Chlorine . . . . 24·74
100·00

whence, putting

$\alpha^m\chi^{m_1}\varrho_1^{m_2}$ as the symbol of chloride of silver,
$\alpha^n\chi^{n_1}\varrho_1^{n_2}$ as the symbol of silver,
$\alpha\chi^2$ as the symbol of chlorine,

$$y_1\alpha^m\chi^{m_1}\varrho_1^{m_2}=y_2\alpha\chi^2+y_3\alpha^n\chi^{n_1}\varrho_1^{n_2};$$

and

$$\begin{aligned} y_1m &= y_2+y_3n, \\ y_1m_1 &= 2y_2+y_3n_1, \\ y_1m_2 &= y_3n_2, \end{aligned}$$

and putting W as the density of the vapour of silver,

$$\frac{y_3 \mathrm{W}}{y_2} = \frac{35{\cdot}5 \times 75{\cdot}24}{24{\cdot}66} = 108,$$

whence we may infer that

$$\frac{y_3 \mathrm{W}}{y_2} = 2\mathrm{A}.$$

Also from the general considerations previously given,

$$\frac{y_3 \mathrm{W}}{y_1} = \mathrm{XA},$$

where X is a positive integer.

Hypothesis I.—Let us assume that W=A. Then

$$\frac{y_3}{y_2} = 2, \quad \frac{y_3}{y_1} = \mathrm{X}, \text{ and } \frac{y_2}{y_1} = \frac{\mathrm{X}}{2}.$$

There are two cases, according as X is assumed to be odd or even.

(1) Let $\mathrm{X}=2x+1$, an odd number. Then $y_1=2$, $y_2=\mathrm{X}$, $y_3=2\mathrm{X}$; and substituting these values in the equation

$$y_1 m = y_2 + y_3 n,$$

we have

$$2m = (2x+1)(1+2n),$$

to which equation there is no integral solution. This hypothesis is therefore untenable.

(2) Let $\mathrm{X}=2x_1$, an even number. Then $y_1=1$, $y_2=x_1$, $y_3=2x_1$, and

$$\begin{aligned} m &= x_1(1+2n), \\ m_1 &= 2x_1(1+n_1), \\ m_2 &= 2x_1 n_2. \end{aligned}$$

These equations in all cases admit of the minimum solution,

$$\begin{aligned} m &= x_1, & n &= 0, \\ m_1 &= 2x_1, & n_1 &= 0, \\ m_2 &= 2x_1, & n_2 &= 1. \end{aligned}$$

In which case the above equation becomes

$$(\alpha\chi^2\varrho_1^2)^{x_1} = x_1(\alpha\chi^2 + 2\varrho_1),$$

the symbols being thus expressed:

	Symbol.	Weight in grm.	Relative weight.
Silver	ϱ_1	4·827	54
Chloride of silver .	$(\alpha\chi^2\varrho_1^2)^{x_1}$	$x_1 \times 12{\cdot}828$	$x_1 \times 143{\cdot}5$

Hypothesis II.—Now, let W=2A. Then

$$\frac{y_3}{y_2} = 1, \quad \frac{2y_3}{y_1} = \mathrm{X}, \text{ and } \frac{2y_2}{y_1} = \mathrm{X}.$$

(1) Let X be odd, $=2x+1$; then $y_1=2$, $y_2=\mathrm{X}$, $y_3=\mathrm{X}$, and

$$\begin{aligned} 2m &= (2x+1)(1+n), \\ 2m_1 &= (2x+1)(2+n_1), \\ 2m_2 &= (2x+1)n_2. \end{aligned}$$

These equations in all cases admit of the minimum solution,

$$\begin{aligned} m &= 2x+1, & n &= 1, \\ m_1 &= 2x+1, & n_1 &= 0, \\ m_2 &= 2x+1, & n_2 &= 2, \end{aligned}$$

and the above equation becomes

$$2(\alpha\chi\varrho_1)^{2x+1}=(2x+1)(\alpha\chi^2+\alpha\varrho_1^2),$$

the symbols being thus expressed:

	Prime factor.	Weight in grm.	Relative weight.
	ϱ_1.	4·783	53·5
	Symbol.		
Silver	$\alpha\varrho_1^2$	9·654	108
Chloride of silver .	$(\alpha\chi\varrho_1)^{2x+1}$	$(2x+1)$6·423	$(2x+1)$71·75

(2) If $X=2x_1$, an even number, $y_1=1$, $y_2=x_1$, $y_3=x_1$, and

$$\begin{aligned} m &= x_1(1+n), \\ m_1 &= x_1(2+n_1), \\ m_2 &= x_1 n_2, \end{aligned}$$

which admit of the minimum solution,

$$\begin{aligned} m &= x_1, & n &= 0, \\ m_1 &= 2x_1, & n_1 &= 0, \\ m_2 &= x_1, & n_2 &= 1. \end{aligned}$$

This hypothesis is, however, untenable for the following reason.

According to the definition given of the weight A (Sec. VII. Group 2 (1)), the weight A is the smallest weight of silver formed by the decomposition of the unit of any chemical substance. Hence, if y be the number of units of the substance decomposed, and x the number of units of silver in that equation in which the weight A appears,

$$\frac{xW}{y}=A.$$

And putting ϱ_1 as the symbol of silver,

$$y\varrho_1^t=x\varrho_1,$$

and

$$ty=x:$$

but since $W=2A$, $y=2x$, whence $2t=1$, to which equation there is no integral solution. This hypothesis is therefore to be rejected.

If, however, in the above equation we select 2 as the value of n_2,

$$\begin{aligned} m &= x_1, \\ m_1 &= 2x_1, \\ m_2 &= 2x_1, \end{aligned}$$

in which case

$$(\alpha\chi^2\varrho_1^2)^{x_1}=x_1(\alpha\chi^2+\varrho_1^2);$$

and we have

$$y\varrho_1^t=x\varrho_1^2,$$

and $ty=2x$ and $t=1$.

It appears, therefore, that so far as any information extends which is afforded to us by the specific heat of silver, the symbol of this metal may be regarded as identical in form with that of zinc or mercury, the equation under consideration being expressed thus,

$$\alpha\chi^2\varrho_1^2=\alpha\chi^2+2\varrho_1,$$

or as being similar to the equation which expresses the relation existing between mercurous chloride and its elements,

$$\alpha\chi^2\delta^2=\alpha\chi^2+2\delta.$$

Or again, it may also be regarded as identical in form with the symbols of chlorine and of nitrogen; in which case the above equation is thus expressed,

$$2\alpha\chi\varrho_1=\alpha\chi^2+\alpha\varrho_1^2,$$

and is similar to the equation which connects the symbols of the chloride of iodine with those of chlorine and iodine,

$$2\alpha\chi\omega=\alpha\chi^2+\alpha\omega^2.$$

And, lastly, the facts are not even inconsistent with the assumption that the symbol of silver is identical in form with the symbols of oxygen and sulphur, so that

$$\alpha\chi^2\varrho_1^2=\alpha\chi^2+\varrho_1^2,$$

which is similar to the equation which connects the symbol of the bisulphide of chlorine with the symbols of its elements

$$\alpha\chi^2\theta^2=\alpha\chi^2+\theta^2.$$

The symbols of silver and its compounds appear, on the two more probable hypotheses, as follows:

Hypothesis I. W=A, X=$2x_1$.

Name.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ϱ	4·827	54
	Symbol.		
Silver	ϱ_1	4·827	54
Oxide of silver	$\varrho_1^2\xi$	10·369	116
Sulphide of silver	$\varrho_1^2\theta$	11·085	124
Sulphate of silver	$\varrho_1^2\theta\xi^4$	13·945	156
Chloride of silver	$\alpha\chi^2\varrho_1^2$	12·828	143·5
Nitrate of silver	$\alpha\nu^2\varrho_1^2\xi^6$	15·197	170
Metaphosphate of silver	$\alpha\phi^2\varrho_1^2\xi^6$	16·716	187
Pyrophosphate of silver	$\alpha\phi^2\varrho_1^4\xi^7$	27·086	303
Orthophosphate of silver	$\alpha\phi^2\varrho_1^6\xi^8$	37·455	419
Cyanide of silver	$\alpha\nu^2\varrho_1^2\kappa^2$	11·979	134

Hypothesis II. $W=2A$, $X=2x+1$.

Name.	Prime factor.	Absolute weight, in grammes.	Relative weight.
	ϱ_2	4·782	53·5
	Symbol.		
Silver	$\alpha\varrho_2{}^2$	9·654	108
Oxide of silver	$\alpha\varrho_2{}^2\xi$	10·369	116
Sulphide of silver	$\alpha\varrho_2{}^2\theta$	11·085	124
Sulphate of silver	$\alpha\varrho_2{}^2\theta\xi^4$	13·945	156
Chloride of silver	$\alpha\chi\varrho_2$	6·414	71·75
Nitrate of silver	$\alpha\nu\varrho_2\xi^3$	7·598	85
Metaphosphate of silver	$\alpha\varphi\varrho_2\xi^3$	8·358	93·5
Pyrophosphate of silver	$\alpha^3\varphi^2\varrho_2{}^4\xi^7$	27·086	303
Orthophosphate of silver	$\alpha^2\varphi\varrho_2{}^3\xi^4$	18·728	209·5
Cyanide of silver	$\alpha\nu\varrho_2\kappa$	5·989	67

This example may serve to show how inadequate are those considerations which are frequently regarded as affording a satisfactory solution of these important problems. If we are to pronounce an opinion on such slender data, the more probable hypothesis seems to be that which associates silver and the allied metals with the other electropositive elements. In the two cases (namely mercury and cadmium) in which the fact can be experimentally determined, $W=A$. In other instances also, such as that of zinc, there is every reason to believe that this is the case.

As hypotheses thus accumulate the probability diminishes of the conclusions which are based upon them. It is, however, to be remembered that such uncertainty is not peculiar to chemistry, but that in every inductive science our exact knowledge lies within a very narrow sphere, as compared with the total field of observation; and after every deduction has been made on this account, there remains, as the solid nucleus of the science, the combinations of carbon and the gaseous elements, which hold in the theory of chemistry a position somewhat analogous to that occupied in astronomy by our solar system, as the area of exact observation.

SECTION VIII.—ON THE APPARENT EXCEPTIONS TO THE LAW OF PRIME FACTORS.

(1) On proceeding with the construction of the symbols of chemical substances, it will be found that in a certain limited number of cases the primary equations are apparently of such a nature as to render impossible the expression in them of the symbols by means of the same system of prime factors α, χ, ξ, . . . by which the symbols in other cases can be expressed. It is probable that this anomaly admits of a very simple explanation, but it is not without interest to consider the modifications which such a fact, if it were truly established, would render necessary in our chemical ideas.

The density of sal-ammoniac in the gaseous condition, as experimentally determined, is 14·44, so that 4 volumes of sal-ammoniac are apparently decomposed into 4 volumes of hydrogen, 1 volume of chlorine, and 1 volume of nitrogen. Whence, putting $\alpha^{m}\chi^{m_1}\nu^{m_2}$ as the symbol of the unit of sal ammoniac,

$$(\alpha^{m}\chi^{m_1}\nu^{m_2})^4=\alpha^4\alpha\chi^2\alpha\nu^2,$$

and

$$\begin{aligned}2m&=3,\\2m_1&=1,\\2m_2&=1,\end{aligned}$$

and the symbol of sal-ammoniac is $(\alpha^3\chi\nu)^{\frac{1}{2}}$, and cannot be expressed by an integral number of the prime factors α, χ, ν.

We may now inquire whether, seeing this expression of the symbol of chloride of ammonium to be impossible on the assumption that the symbols of the elements hydrogen, chlorine, and nitrogen are of the forms α, $\alpha\chi^2$, $\alpha\nu^2$, it be possible on any other hypothesis as to these symbols, consistent with known facts. Now every possible hypothesis as to these symbols consistent with their expression by an integral number of prime factors in the equations from which the symbols have been derived, and with the expression of the symbol of hydrogen by one prime factor, α, is, as has been shown (Sec. VII. (5) and (8)), implicitly contained in the general forms of the symbols of chlorine and nitrogen, which are respectively $\alpha^{1+2p}\chi^{2(1+p_1)}$ and $\alpha^{1+2q}\nu^{2(1+q_1)}$; whence, putting

$$(\alpha^{m}\chi^{m_1}\nu^{m_2})^4=\alpha^4\alpha^{1+2p}\chi^{2(1+p_1)}\alpha^{1+2q}\nu^{2(1+q_1)},$$

$$\begin{aligned}2m&=3+\overline{p+q},\\2m_1&=1+p_1,\\2m_2&=1+q_1,\end{aligned}$$

and

$$\begin{aligned}m&=2, & p+q&=1,\\m_1&=1, & p_1&=1,\\m_2&=1; & q_1&=1,\end{aligned}$$

a minimum.

On the hypothesis, $p=0$, $q=1$, we have

Symbol of chlorine $\alpha\chi^4$,
Symbol of nitrogen $\alpha^3\nu^4$.

On the hypothesis, $p=1$, $q=0$, we have

Symbol of chlorine $\alpha^3\chi^4$,
Symbol of nitrogen $\alpha\nu^4$.

Neither hypothesis is absolutely inconsistent with any known fact, for it is possible thus to express the symbols of chlorine and nitrogen in every equation into which those symbols enter; and if it were placed beyond doubt that the true density of chloride of ammonium in the gaseous condition were 12·88, we might thus accept the fact and assert that the factors χ and ν were composite, so that either $\chi=\chi_1^2$ and $\nu=\alpha^2\nu_1^2$, or $\chi=\alpha^2\chi_2^2$ and $\nu=\nu_2^2$, and our view of the possible system of chemical substances, and of the laws of combination to which they were subject, would be profoundly modified. I am far from believing that such is the true solution of this apparent anomaly. Such a solution, although not absolutely precluded to us, is in the highest degree improbable; and the facts admit of an obvious and simple explanation on the hypothesis that chloride of ammonium is decomposed, at the temperature at which its vapour-density is supposed to have been taken, into equal volumes of hydrochloric acid and ammonia, of which very satisfactory evidence has been given[*].

(2) Again, the density of the binoxide of nitrogen is 14·989, as determined by experiment. If this be correct, 2 volumes of binoxide of nitrogen are decomposed into 1 volume of nitrogen and 1 volume of oxygen; whence, putting $\alpha^{m}\nu^{m_1}\xi^{m_2}$ as the symbol of the binoxide, $\alpha\nu^2$ as the symbol of nitrogen, and ξ^2 as the symbol of oxygen,

$$(\alpha^{m}\nu^{m_1}\xi^{m_2})^2=\alpha\nu^2\xi^2,$$

and

$$2m=1,$$
$$m_1=1,$$
$$m_2=1,$$

and the symbol of the binoxide of nitrogen, as expressed by the factors α, ν, ξ, is $\alpha^{\frac{1}{2}}\nu\xi$.

If we now inquire, as before, whether any hypothesis as to the symbols of nitrogen and oxygen can be made which shall be consistent with the fundamental assumption that the symbol of hydrogen is expressed by one factor, we have, putting $\alpha^{2p}\xi^{2(1+p_1)}$ and $\alpha^{1+2q}\ \nu^{2(1+q_1)}$ as the general symbols of oxygen and nitrogen (Sec. VII. (2) and (8),

$$(\alpha^{m}\nu^{m_1}\xi^{m_2})^2=\alpha^{1+2q}\nu^{2(1+q_1)}\alpha^{2p}\xi^{2(1+p_1)},$$

and

$$2m=1+2(q+p),$$
$$m_1=1+q_1,$$
$$m_2=1+p_1.$$

Now no positive and integral solution as regards m, q, and p, can be found which shall satisfy the first of these equations. The above equation, therefore, which expresses the relation which exists between the ponderable matter of the binoxide of nitrogen and its elements, is incompatible with the expression of the symbols by an integral number of prime factors, on the assumption that the symbol of hydrogen is α.

The anomaly in the density of the binoxide of nitrogen was long since observed by LAURENT and GERHARDT, who discovered the empirical law of even numbers. But such has been the influence upon the mind of chemists of an arbitrary hypothesis as to the constitution of matter, and of an uncertain system of notation, that this anomaly, the most singular exception known to the general laws of chemistry, is even now imperfectly recognized, and has never yet been submitted to any serious or adequate investigation.

(3) The following are the chief exceptions, real or apparent, to the law of prime factors[†].

---

[*] See PEBAL, Ann. Chem. Pharm., vol. cxxiii. p. 199.

[†] See LAURENT's Chemical Method, p. 81; WATTS's Dictionary of Chemistry, vol. i. p. 469; GERHARDT, Traité de Chimie, vol. i. p. 581, vol. iv. p. 897.

The second column contains the symbol, as expressed by the factors α, χ, ξ, ... ; the third column the temperatures at which the observation is made; column A, the density of the substance, the density of air being assumed as 1; column B, the same density, the density of hydrogen being 1; column C contains the density as calculated from the symbols given in the first column.

Substance.	Symbol.	Temp. C.	A.	B.	C.
Binoxide of nitrogen	$\alpha^{\frac{1}{2}}\nu\xi$	. . . .	1·038	14·989	15
Peroxide of nitrogen	$\alpha^{\frac{1}{2}}\nu\xi^2$	. . . .	1·527	22·050	23
,, ,,	,,	97·5	1·783	25·746	,,
,, ,,	,,	24·5	2·520	36·389	,,
,, ,,	,,	11·3	2·645	38·194	,,
Mercurous chloride	$\alpha^{\frac{1}{2}}\chi\delta_1$	. . . .	8·35	120·574	117·75
Chloride of ammonium	$\alpha^{\frac{3}{2}}\chi^{\frac{1}{2}}\nu^{\frac{1}{2}}$	1040	1·00	14·44	13·375
Bromide of ammonium	$\alpha^{\frac{3}{2}}\beta^{\frac{1}{2}}\nu^{\frac{1}{2}}$	. . . .	1·69	24·40	24·5
Iodide of ammonium	$\alpha^{\frac{3}{2}}\omega^{\frac{1}{2}}\nu^{\frac{1}{2}}$	. . . .	2·68	38·77	36·25
Cyanide of ammonium	$\alpha^{\frac{3}{2}}\kappa^{\frac{1}{2}}\nu^{\frac{1}{2}}$	. . . .	0·79	11·41	11
Hydrosulphate of ammonia	$(\alpha^3\nu\theta)^{\frac{1}{2}}$	. . . .	0·89	12·85	12·75
Iodide of phosphonium	$(\alpha^3\omega\phi)^{\frac{1}{2}}$	. . . .	2·77	39·999	40·5
Pentachloride of phosphorus	$(\alpha^3\chi^5\phi)^{\frac{1}{2}}$	182	5·078	73·326	52·125
,, ,,	,,	336	3·656	52·793	,,
Oxychloride of phosphorus	$(\alpha^2\chi^3\phi\xi)^{\frac{1}{2}}$	. . . .	5·40	77·976	76·75
Sulphide of mercury	$(\delta\theta)^{\frac{2}{3}}$	. . . .	5·51	79·564	77·33
Perchlorinated methylic ether	$\alpha^{\frac{3}{2}}\chi^3\kappa\xi^{\frac{1}{2}}$	. . . .	4·67	67·435	63·25
Perchlorinated sulphide of methyl. .	$\alpha^{\frac{3}{2}}\chi^3\kappa\theta^{\frac{1}{2}}$	. . . .	5·68	82·019	67·25

It will be seen on inspection of the preceding Table that, in many instances, the vapour-density, as determined by experiment, does not sufficiently agree with any hypothesis even remotely probable.

Many of these apparent exceptions obviously admit of a similar simple explanation to that which has been suggested in the case of chloride of ammonium. Indeed, it would be truly surprising if in the varied transformations of matter no example of such decomposition should occur. In more than one case actual evidence of it has been adduced[*]; and while undoubtedly it must be allowed that the question is not to be answered by theoretical considerations alone, but that every case of such apparent anomaly should be submitted to the most rigid tests of experiment, there is every reason to believe that the simple weights α, ξ, θ, χ, ... are the ultimate known components of the units of ponderable matter, and represent a limit to chemical decomposition which has not as yet been passed.

---

[*] See PLAYFAIR and WANKLYN, Journ. Chemical Society, vol. xv. p. 142; WANKLYN and ROBINSON, "On Diffusion of Vapours," Proceedings, Royal Society, vol. xii. p. 507.

The atomic theory may be compared to a sort of "abacus" or simple mechanical instrument which chemists have invented to facilitate their calculations. It is useless to pretend that any demonstration can be given of this theory, which, at best, can only be regarded as a possible hypothesis suggested by the facts; but nevertheless it has a very real claim upon our consideration from the practical advantages which it has afforded in the study of the science. The atoms of the chemist fulfil a similar purpose in his calculations to that fulfilled by balls in the estimation of probabilities. They afford a simple and not inaccurate image of the subject with which he is concerned, by which he is enabled to reduce his problems to a concrete form, and thus at once to realize and to isolate them. To forbid the use of such an image would be to impose a very unnecessary restriction upon scientific methods. A ball as the concrete symbol of an indivisible whole, may advantageously represent, as occasion requires, a unit of weight, a simple weight, an event. We are perfectly free, when it suits our purpose, to make use of such conceptions. It is, however, a fatal illusion to mistake the suggestions of fancy for the realities of nature, and such a symbol becomes open to serious objection unless we carefully discriminate between conjecture and fact. Under the baneful influence of such hypotheses the methods of positive science lose their hold upon the mind, until at length we are actually informed by the consistent advocates of these ideas that the science of chemistry has no other field for its activity than the obscure region of atomic speculations.

Now a symbolic calculus affords the same indispensable aid which is given by the atomic theory, but in a more truthful and effectual way. In the place of molecules and atoms it offers, as the subject of scientific contemplation, a system of marks and combinations of letters, which, however, we are not free to arrange and to interpret according to the dictates of caprice, but of which each has a specific meaning assigned to it in the calculus, from which the laws are deduced according to which it is permitted to operate upon it. We are thus enabled to construct an accurate symbolic representation of the phenomena before us, on the fidelity of which we can rely. Such a system is indeed based, in the most absolute sense, upon fact, for it presents only two objects to our consideration, the symbol and the thing signified by the symbol, the object of thought and the object of sense; and it is not the least among the advantages which such a method affords, that through it we are enabled to dispense altogether with less truthful modes of representation, as no longer calculated to serve even a useful purpose.

Every mark or sign which we employ for the purposes of thought is in a certain sense a symbol, and in their actual system of chemical notation, chemists are already in possession of an imperfect symbolic method. It appeared to me inexpedient to attempt any interference with this method, which has already been subject to so many modifications, and which, moreover, satisfies certain real demands. I must confess also that it seemed to me incapable of development, as being destitute of those essential conceptions, in the growth of which the development of such a method consists.

Now it is the introduction of the conception of chemical operations which, as has before been said, especially distinguishes this calculus. The symbols here employed are symbols not of quantities (which may be replaced by numbers), but of operations (which cannot be thus replaced), which are defined by their results; and the units of ponderable matter are primarily conceived of in this calculus as made up from their component weights by the successive performance upon the unit of space of the operations indicated by the symbols of those weights.

It is through this order of conceptions that we are enabled to introduce into the chemical calculus the zero-symbol 1, regarded as the symbol of the unit of space, the subject of chemical operations, without which symbol, as will hereafter be still more clearly evident, the construction of a chemical calculus would appear to be impossible, and the absence of which symbol, perhaps more than any other defect, marks the radical imperfection of the present notation.

It is moreover from this point of view that it has been found possible to assign to the composite symbol xy, as the symbol of a compound weight, an exact interpretation in harmony with symbolic analogies, and it is as symbols of operation that chemical symbols have been proved to possess the properties given in the equations

$$xy=yx,$$
$$x(y+y_1)=xy+xy_1,$$
$$xy=x+y,$$

which afford an adequate basis for a symbolic method, and enable us to apply to these symbols those algebraic processes through which symbols become an instrument of reasoning.

But further, symbols of this class afford the most real and the most obvious expression of the facts with which the chemist deals. That such operations as are here indicated are the primary and immediate object of his study, and therefore the most essential particular to be embodied in the symbol, has been already, to a certain extent, recognized by more than one master of the science, adverse to the atomic mode of representation. Thus GERHARDT, in the remarkable words which I have placed as a fitting motto to this paper, thus defines the object of a chemical formula. "Les formules chimiques, comme nous l'avons dit, ne sont pas destinées à représenter l'arrangement des atomes, mais elles ont pour but de rendre évidentes, de la manière la plus simple et la plus exacte, les relations qui rattachent les corps entre eux sous le rapport des transformations"*. Now if this be the object of a formula, how unreasonable is it to attempt the expression of that formula by symbols which not only permit, but even compel us to regard it from the atomic point of view. We cannot adopt the atomic symbol and at the same time declare ourselves free from the atomic doctrines. The symbols which are here employed impose no such limitation upon our view. They are simply the symbols of the operations, from whatever point of view these operations may be regarded, by which chemical transformations are effected. In the symbol of the unit of water $\alpha\xi$, we assert an indisputable fact as to the operations by which that unit is composed and decomposed in the actual system of chemical transformations. The symbol asserts that the unit of water is composed by two indivisible operations—indivisible, that is, so far as our experience extends—operating successively upon the unit of space, which are known to us through their results and are defined by their results. Again, we assert that the units of certain other substances are similarly composed, the units of hydrochloric acid and of hydrosulphuric acid, for example, of which $\alpha\chi$ and $\alpha\theta$ are the symbols, and that in this respect these substances are similar to water. Or, again, we say that the units of hydrogen, of water, and of peroxide of hydrogen are connected by a certain serial relation between the operations by which they are composed which is given by the interpretation of the symbols α, $\alpha\xi$, $\alpha\xi^2$, and that this relation is similar to that which exists between the units of hydrogen, hydrochloric acid, and chlorine, α, $\alpha\chi$, $\alpha\chi^2$. Now these are those very relations "qui rattachent les corps entre eux sous le rapport des transformations," which GERHARDT discerned to be the true object of symbolic expression, but which are not indicated, except accidentally, by our present system, which is based upon a different order of ideas.

---

* Chimie Organique, Paris, 1856, vol. iv. p. 566.

But there is another aspect of the science equally real with that in which GERHARDT regarded it, and which he declined to consider. Surely we may be permitted to ask with DALTON, not only by what operations water is composed, but what water *is*? What is the nature of ponderable matter as revealed to us by the science of Chemistry? To this inquiry also, in the only form in which such an inquiry is real and intelligible, the symbol supplies an answer. This answer is given by interpreting the symbol with reference to the results of the operations. The unit of water (Sec. I. Def. 10), we may reply to such a question, is an integral compound weight (Sec. I. Def. 7) of which the whole is identical with the two simple weights (Sec. I. Def. 8) α and ξ of Section VII., which we recognize as simple weights from the fact that in the total system of chemical transformations these weights are not distributed (Sec. I. Def. 12). The science of Chemistry, we may add, affords no further information whatever as to the composition of water than that which is comprised in this assertion, which is not only the true but the only real form of answer which it is possible to give to inquiries as to the chemical composition of ponderable matter. There is no difference whatever, as regards facts, between this and the preceding statement; the difference lies in the way in which the facts are regarded. From the former point of view we consider the operations, from the latter the result of the operations. The symbols of geometry have a similar double interpretation. They may be regarded, with equal truth, as the symbols of lines and surfaces, or of the operations by which lines and surfaces are generated.

A symbol, however, should be something more than a convenient and compendious expression of facts. It is, in the strictest sense, an instrument for the discovery of facts, and is of value mainly with reference to this end, by its adaptation to which it is to be judged. Now in the present paper I have considered not only the principles of the chemical calculus, as regards the formal construction of symbols, but also the primary application of these principles to the construction of a special symbolic system. In the symbol of each chemical substance a distinct assertion is made as to the chemical properties of the substance, which any one is at liberty to test by an appeal to facts. Now as no symbolic system similar to the present has yet been devised, and as this system cannot be deduced from any existing system, every symbol not only makes an assertion but expresses a discovery as to the chemical properties of the substance symbolized. It is obvious, from the way in which the symbol is constructed, that the properties symbolized are the properties of that system of chemical equations into which the symbols enter, and from which the laws of the science are to be deduced. The further development of these ideas must be reserved for another communication, in which the nature of the numerical laws which are thus expressed will be more fully considered.

We may also regard the symbolic system as the expression, in the language of reason, of those conceptions as to the composition of ponderable matter to which we are inevitably brought by the contemplation of chemical phenomena. Our conclusions on this point are so remarkable, and so contrary to anticipation, that doubtless we could never trust them but for the simple and exact process by which they are deduced. Now the conceptions which we form of the nature of the elemental bodies constitute the fundamental theory of the science, for these conceptions comprise and determine every similar conception. The unit of the element hydrogen is here conceived of as a simple weight, and symbolized by the letter α. That, to say the least, this view may be permitted is proved by constructing the symbols of chemical substances upon this hypothesis. There are, however, certain exceptions, be they real or apparent, in which this mode of expression is impossible, and it will be seen on reference to the table of exceptions (Sec. VIII. (4)) that this hypothesis rejects as inadmissible, not only the cases which are rejected by the atomic theory, but those also which are rejected by the empirical law of even numbers (p. 786). The symbolic system which is here given is the expression of these laws, by the truth of which it must stand or fall. The unit of the element mercury, and the units of several other metals, such as zinc, cadmium, and tin, so far as our imperfect experience extends, appear to be analogous in this respect to hydrogen. But these are the only elements of this simple composition. The units of a second group, of which the element oxygen, symbolized as ξ^2, may be taken as a type, and to which belong sulphur, θ^2, and selenium, λ^2, are composed of two identical simple weights, and the facts of the science do not permit us to assume these units as otherwise composed. Lastly, another group of elements appears in this system of a different and more complex composition, to which group belong the elements chlorine $\alpha\chi^2$, bromine $\alpha\beta^2$, iodine $\alpha\omega^2$, nitrogen $\alpha\nu^2$, phosphorus $(\alpha\varphi^2)^2$, arsenic $(\alpha\zeta^2)^2$, and in all probability numerous other elements. The simplest view which, consistently with the fundamental hypothesis (Sec. VII. Group 1 (1)), can be taken of the composition of these elements, regard being had to the total system of chemical combinations, is that they are severally composed of a unit of hydrogen and of two identical simple weights, as, for example, in the case of chlorine, of the simple weight α and two of the simple weights symbolized by χ, so that the elements of this group are to be considered as combinations of elements of the two previous forms respectively. It is further found, as a matter of experience, that the unit of every chemical substance may be regarded as a combination of the same simple weights, α, ξ, θ, χ, ω, ν, ..., which are the component weights of the units of the elements. Now from the fundamental equation $xy=x+y$,

$$\xi^2=2\xi,$$

$$\alpha\chi^2=\alpha+2\chi,$$

$$\alpha^2\phi^4=2\alpha+4\phi,$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

whence we unavoidably have suggested to us as the ultimate origin of our actual system of combinations, and as affording an adequate and probable (doubtless we cannot say the only possible or conceivable) explanation of the peculiar phenomena there presented to us, a group of elements ξ, θ, χ, β, ω, ν, ϕ, ... of the densities indicated by these symbols, and which, though now revealed to us through the numerical properties of chemical equations only as "implicit and dependent existences," we cannot but surmise may some day become, or may in the past have been, "isolated and independent existences." Examples of these simple monad forms of material being are preserved to us in such elements as hydrogen and mercury, which appear in the chemical system, as records suggestive of a state of things different from that which actually prevails, but which has passed away, and which we are unable to restore.

Such a hypothesis is not precluded to us, but nevertheless we are not to imagine that it is a necessary inference from the facts. So far as the principles or conclusions of this method are concerned, the "simple weights" ξ, θ, χ, β, ω, ν, ϕ, . . . may be treated purely as "ideal" existences created and called into being to satisfy the demands of the intellect, to enable us to reason and to think in reference to chemical phenomena, but destined to vanish from the scene when their purpose has been served; and the existence of which as external realities we neither assume nor deny.

XXVII. *On the Expansion by Heat of Metals and Alloys.* *By* A. Matthiessen, *F.R.S.*

Received June 20,—Read June 21, 1866.

In a memoir "On the Expansion by Heat of Water and Mercury"*, I described a method of determining the expansion of bodies by weighing them in water at different temperatures. This method was chosen on account of its yielding accurate results with comparatively small quantities, for to purify large quantities of metal would entail immense labour and expense; so much so, in fact, that to purify sufficient quantities to make bars for the determination of the linear expansion would be practically impossible.

On determining the expansion of the metals by this method, I found that they did not expand regularly between 0° and 100°. The difference, however, between the rates of expansion between 0° and 50° and 50° and 100° was found to be so great that part of it might be possibly attributed to errors in the determination of the coefficients of expansion of water, as the coefficients of expansion of the metals are comparatively small when compared with those of water. Now, although the coefficient of expansion of mercury when determined by this method agrees with Regnault's value, yet on account of this value being large, small errors in the water coefficients will not materially influence it; for the volume of water at

$$4°=1{\cdot}0000, \text{ at } 100°=1{\cdot}04316,$$

that of mercury at

$$0°=1{\cdot}0000, \text{ at } 100°=1{\cdot}01815,$$

and that of copper, for instance, at

$$0°=1{\cdot}00000, \text{ at } 100°=1004998,$$

showing that the expansion of copper is very small compared with that of water or mercury.

This fact led me to make another series of check experiments by determining the linear expansion of a certain copper bar, as described in the first part of my paper above quoted, and then weighing a piece of it, turned to the shape of a double cone, in water at different temperatures.

The following are the results obtained with the copper bar; and it may here be mentioned that copper does not behave in one respect like glass. The glass rods, as there shown, do not return directly to their original length after being heated to 100° and cooled rapidly; copper, however, does so; for no differences in the coefficients were observed after heating the rod to 100°, determining its expansion, allowing it to stand over night, and redetermining the coefficients.

---

* Philosophical Transactions, 1866, Part I.

In Table I., T, T_1, T_2, T_3, T_4 indicate the temperatures in the order in which the observations were made; a, b, c the increment in length in millims. of the rod between T_1 and T_2, T_1 and T_3, T and T_3 respectively; the values in the three last columns are the coefficients of expansion of the rod between the observed temperatures. The length of the rod was 1804 millims. and its diameter about 15 millims.

TABLE I.

T_1.	T_2.	T_3.	T_4.	a.	b.	c.	$\frac{a}{T_2-T_1}$.	$\frac{b}{T_3-T_1}$.	$\frac{c}{T_3-T_4}$.
7·4	......	99·9	7·0	......	2·807	2·803	....	0·03034	0·03017
7·0	50·7	100·1	10·4	1·263	2·808	2·718	0·02890	0·03016	0·03030
8·4	51·2	100·3	7·0	1·252	2·807	2·830	0·02925	0·03054	0·03033
7·5	51·9	100·3	7·8	1·295	2·805	2·803	0·02917	0·03023	0·03030
8·6	50·9	100·6	7·2	1·238	2·775	2·812	0·02927	0·03016	0·03011
			Mean	....	0·02915	......	0·03026		

Or the mean coefficient between 0° and 50° may be taken $=0·02915$, and that between 0° and $100°=0·03026$.

And taking the length of the rod at $0°=1804$, it will be

$$\text{at } 50°=1805·4575,$$
$$\text{at } 100°=1808·0260.$$

From these values the linear expansion of the copper rod can be expressed by the formula

$$L_t=1804(1+0·00001555t+0·0000000122t^2),$$

or for any length of this sort of copper the formula for the correction of the linear expansion for temperature will be

$$L_t=L_0(1+0·00001555t+0·0000000122t^2),$$

and that for the correction of the cubical expansion

$$V_t=V_0(1+0·00004665t+0·0000000366t^2).$$

Two series of weighings in water were made with the piece cut from the end of the copper rod; the results are given in Table II.

TABLE II.

No. 1.

	Loss of weight in water $=W$.	$W(1+at)$.
11·0	3·95740	3·95885
50·7	3·91825	3·96640
97·1	3·81940	3·97590

No. 2.

10·6	3·95720	3·95850
54·2	3·91220	3·96685
97·3	3·81865	3·97570

The copper was slightly gilded to prevent the action of the water on it; the water being reboiled before each weighing to drive out any absorbed air. The values given in the third column express the volume of the copper in cubic centimetres, and are deduced from the observed loss of weight in water W, as described (p. 245) in the paper already quoted. Calculating formulæ to express the volumes of copper at different temperatures, we find for

No. 1.

$$V_t=3{\cdot}95680(1+0{\cdot}00004645t+0{\cdot}0000000336t^2),\text{ or if }V_a=1,\text{ then }V_{100}=1{\cdot}004981;$$

No. 2.

$$V_t=3{\cdot}95655(1+0{\cdot}00004681t+0{\cdot}0000000300t^2),\text{ or if }V_0=1,\text{ then }V_{100}=1{\cdot}004981,$$

formulæ agreeing closely with that deduced from the determination of the linear expansion of the copper rod, namely,

$$V_t=V_0(1+0{\cdot}00004665t+0{\cdot}0000000366t^2),\text{ or if }V_0=1,\text{ then }V_{100}=1{\cdot}005031.$$

This memoir may be divided into two parts:—

I. *On the Expansion by Heat of the Metals.*

II. *On the Expansion by Heat of Alloys.*

I. *On the Expansion by Heat of the Metals.*

The metals employed for these experiments were purified in the manner described in a former paper [*], and cast in a well-smoked mould, which gave the casting the shape of a double wedge, as shown in fig. 7 [†]. Owing to the action of the water on some of the metals and alloys, the castings had in some cases to be varnished or gilded, the latter method being more generally used. To prove that the gilding or varnishing had no influence on the results, some of those metals on which water has no action were varnished or gilded in the one series and not in the other (Series Nos. 3 and 4, 14 and 15, 11 and 12).

The disposition of the apparatus and the method of observation was the same as described in the paper "On the Expansion of Water and Mercury."

Sometimes observations were made commencing at the highest temperature, and cooling down without boiling out the water between the determinations made at the different temperatures. (The series made in this manner will be headed once boiled.)

At others the observations were first taken at the lowest temperature, the water reboiled, then those at the highest temperature, and afterwards on cooling those at the intermediate one (twice boiled).

And again, at others the water was reboiled between each set of observations (thrice boiled).

It may be as well to point out some of the causes of failure in this method of determining the coefficients of expansion; for although it appears a very simple one, yet it requires, I may say, very great care to ensure reliable results.

---

[*] Philosophical Transactions, 1860, p. 177.

[†] Philosophical Transactions, 1866, Plate XX.

I. Very often a series was rendered valueless by small hairs or particles of dust falling into the water and attaching themselves to the fine platinum wire, as 0·1 or 0·2 milligramme difference in the weight makes a considerable difference in the expansion of those metals or alloys which have a low coefficient of expansion; this source of error was carefully guarded against; in fact, if on taking the cylinder out to reboil the water any particle of dust floated near the wires, the observations were considered worthless, and fresh ones taken after reboiling the water.

II. When, for instance, the observations were being made at the highest temperature, if by chance the temperature sunk three or four degrees and gradually rose again, the air absorbed at the lower temperature would be expelled, and an air-bubble would sometimes attach itself to the metal and cause a false weighing.

III. If the casting were not perfect, or were crystalline, and the air could not be completely expelled from the small cavities by boiling, results were obtained which did not agree together, owing to its expansion at the high and partial absorption by the water at the lower temperature. For this reason two series were always made with each metal and alloy, and where possible they were recast.

The values obtained when weighing the purified metals in water were as follow:—

TABLE III.—Cadmium.

Owing to this metal becoming crystalline at about 80°, four observations were made between 0° and 100°. It will be seen that this change of molecular condition has no effect on this physical property.

No. 3.—Cadmium, four times boiled.

T.	Loss of weight in water = W.	W(1+*at*).	Calculated.	Difference.
8·0	6·29175	6·29250	6·29241	+0·00009
45·4	6·25080	6·31280	6·31309	−0·00029
77·4	6·16450	6·33255	6·33249	+0·00015
95·2	6·10230	6·34380	6·34377	+0·00003

$V_t=6{\cdot}28826(1+10^{-4}0{\cdot}7991t+10^{-6}\times 0{\cdot}163t^2)$*, or if $V_0=1$, then $V_{100}=1{\cdot}009611$.

No. 4.—Cadmium varnished, four times boiled.

8·1	5·91135	5·91210	5·91182	+0·00028
47·9	5·86800	5·93265	5·93274	−0·00009
75·2	5·79895	5·94885	5·94885	0·00000
93·8	5·73915	5·96040	5·96065	−0·00025

$V_t=5{\cdot}90793(1+10^{-4}0{\cdot}7991t+10^{-6}\times 0{\cdot}163t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}009611$.

---

* I have employed this method of writing the formulæ to prevent mistakes in the number of the zeros, as well as to show at a glance their number. I have also preferred keeping the exponents constant, adding, instead of altering them, a zero after the decimal point where required.

Table III. (continued.)

No. 5.—Zinc varnished, thrice boiled.

T.	Loss of weight in water = W.	W(1+at).
10·0	7·42245	7·42445
50·6	7·35985	7·45000
95·7	7·19460	7·48200

$V_t=7{\cdot}41863(1+10^{-4}\times 0{\cdot}7719t+10^{-6}\times 0{\cdot}126t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008979$.

No. 6.—Zinc varnished, thrice boiled.

9·0	6·69705	6·69830
50·6	6·64010	6·72285
95·0	6·49345	6·74945

$V_t=6{\cdot}69304(1+10^{-4}\times 0{\cdot}8726t+10^{-6}\times 0{\cdot}0153t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008879$.

No. 7.—Lead varnished, once boiled.

14·0	4·55540	4·55880
51·2	4·51635	4·57295
94·1	4·41840	4·58960

$V_t=4{\cdot}55355(1+10^{-4}\times 0{\cdot}8215t+10^{-6}\times 0{\cdot}0210t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008425$.

No. 8.—Lead varnished, once boiled.

14·7	4·40320	4·40695
52·9	4·36270	4·42090
90·7	4·27960	4·43500

$V_t=4{\cdot}40166(1+10^{-4}\times 0{\cdot}8140t+10^{-6}\times 0{\cdot}0234t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008374$.

No. 9.—Tin, once boiled.

10·2	3·66860	3·66965
55·0	3·62850	3·68060
93·2	3·55520	3·69070

$V_t=3{\cdot}66730(1+10^{-4}\times 0{\cdot}6237t+10^{-6}\times 0{\cdot}0656t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}006893$.

No. 10.—Tin, once boiled.

8·2	4·28625	4·28680
48·5	4·25005	4·29800
94·8	4·14945	4·31250

$V_t=4{\cdot}28468(1+10^{-4}\times 0{\cdot}5964t+10^{-6}\times 0{\cdot}0922t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}006886$.

No. 11.—Silver gilded, thrice boiled.

10·7	5·33570	5·33750
52·7	5·28040	5·35035
94·3	5·16280	5·36370

$V_t=5{\cdot}33433(1+10^{-4}\times 0{\cdot}5523t+10^{-6}\times 0{\cdot}0335t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}005858$.

Table III. (continued.)

No. 12.—Silver, thrice boiled.

T.	Loss of weight in water=W.	$W(1+at)$.
7·5	5·49925	5·49975
50·5	5·44655	5·51300
97·1	5·37080	5·52845

$V_t=5\cdot49754(1+10^{-4}\times0\cdot5330t+10^{-6}\times0\cdot0475t^2)$, or if $V_0=1$, then $V_{100}=1\cdot005805$.

No. 13.—Copper gilded, twice boiled.

10·2	5·82730	5·82900
59·8	5·74595	5·84280
95·1	5·63155	5·85400

$V_t=5\cdot82644(1+10^{-4}\times0\cdot4223t+10^{-6}\times0\cdot0791t^2)$, or if $V_0=1$, then $V_{100}=1\cdot005014$.

No. 14.—Gold varnished, thrice boiled.

9·1	2·44605	2·44655
45·4	2·42625	2·45030
95·1	2·36250	2·45585

$V_t=2\cdot44565(1+10^{-4}\times0\cdot4008t+10^{-6}\times0\cdot0397t^2)$, or if $V_0=1$, then $V_{100}=1\cdot004405$.

No. 15.—Gold, once boiled.

10·7	2·44415	2·44490
47·8	2·42225	2·44880
93·0	2·36405	2·45380

$V_t=2\cdot44381(1+10^{-4}\times0\cdot4142t+10^{-6}\times0\cdot0276t^2)$, or if $V_0=1$, then $V_{100}=1\cdot004418$.

No. 16.—Bismuth varnished, once boiled.

8·9	4·29915	4·29995
51·2	4·25350	4·30680
96·0	4·14795	4·31455

$V_t=4\cdot29857(1+10^{-4}\times0\cdot3591t+10^{-6}\times0\cdot0294t^2)$, or if $V_0=1$, then $V_{100}=1\cdot003885$.

No. 17.—Bismuth varnished, twice boiled.

11·6	5·16400	5·16625
50·0	5·11255	5·17375
93·5	4·99200	5·18335

$V_t=5\cdot16416(1+10^{-4}\times0\cdot3413t+10^{-6}\times0\cdot0599t^2)$, or if $V_0=1$, then $V_{100}=1\cdot004012$.

No. 18.—Palladium (purified metal, lent by Messrs. Johnson and Matthey), thrice boiled.

7·5	7·48500	7·48700
55·5	7·38975	7·49785
97·5	7·21130	7·50875

$V_t=7\cdot48545(1+10^{-4}\times0\cdot2708t+10^{-6}\times0\cdot0497t^2)$, or if $V_0=1$, then $V_{100}=1\cdot003205$.

TABLE III. (continued.)

No. 19.—Palladium, same piece as used for the last series, repolished, once boiled.

T.	Loss of weight in water=W.	W(1+*at*).
9·8	7·48420	7·48610
56·0	7·38795	7·49785
97·4	7·21140	7·50855

$V_t=748363(1+10^{-4}\times 0{\cdot}3357t+10^{-6}\times 0{\cdot}0629t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}003420$.

No. 20.—Antimony gilded, once boiled.

11·7	6·26320	6·06590
57·2	5·98155	6·07420
97·1	5·84300	6·08245

$V_t=6{\cdot}06396(1+10^{-4}\times 0{\cdot}2686t+10^{-6}\times 0{\cdot}0469t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}003155$.

No. 21.—Antimony gilded, once boiled.

10·9	6·20525	6·20745
61·0	6·11010	6·21705
97·8	5·97670	6·22475

$V_t=6{\cdot}20550(1+10^{-4}\times 0{\cdot}2854t+10^{-6}\times 0{\cdot}0325t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}003179$.

No. 22.—Platinum (purified metal, lent by Messrs. JOHNSON and MATTHEY), twice boiled.

8·5	2·22465	2·22500
56·0	2·19510	2·22775
97·3	2·14215	2·23025

$V_t=2{\cdot}22452(1+10^{-4}\times 0{\cdot}2516t+10^{-6}\times 0{\cdot}0134t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}002650$.

No. 23.—Platinum, same piece as used for the last series, repolished, twice boiled.

6·6	2·22430	2·22440
51·8	2·19890	2·22705
96·7	2·14260	2·22975

$V_t=2{\cdot}22402(1+10^{-4}\times 0{\cdot}2591t+10^{-6}+0{\cdot}0074t^2)$, or if $V_0=1$, then $V_{100}=\ {\cdot}002665$

The means of the foregoing formulæ are put together in Table IV.

TABLE IV.

	Formulæ for correcting the cubical expansion.
Cadmium	$V_t=V_0(1+10^{-4}\times 0{\cdot}8078t+10^{-6}\times 0{\cdot}140t^2)$
Zinc	$V_t=V_0(1+10^{-4}\times 0{\cdot}8222t+10^{-6}\times 0{\cdot}0706t^2)$
Lead	$V_t=V_0(1+10^{-4}\times 0{\cdot}8177t+10^{-6}\times 0{\cdot}0222t^2)$
Tin	$V_t=V_0(1+10^{-4}\times 0{\cdot}6100t+10^{-6}\times 0{\cdot}0789t^2)$
Silver	$V_t=V_0(1+10^{-4}\times 2{\cdot}5426t+10^{-6}\times 0{\cdot}0405t^2)$
Copper*	$V_t=V_0(1+10^{-4}\times 0{\cdot}4463t+10^{-6}\times 0{\cdot}0555t^2)$
Gold	$V_t=V_0(1+10^{-4}\times 0{\cdot}4075t+10^{-6}\times 0{\cdot}0336t^2)$
Bismuth	$V_t=V_0(1+10^{-4}\times 0{\cdot}3502t+10^{-6}\times 0{\cdot}0446t^2)$
Palladium	$V_t=V_0(1+10^{-4}\times 0{\cdot}3032t+10^{-6}\times 0{\cdot}0280t^2)$
Antimony	$V_t=V_0(1+10^{-4}\times 0{\cdot}2770t+10^{-6}\times 0{\cdot}0397t^2)$
Platinum	$V_t=V_0(1+10^{-4}\times 0{\cdot}2554t+10^{-6}\times 0{\cdot}0104t^2)$

The formulæ for the correction of the linear expansion of the above metals may be deduced by dividing the coefficients obtained for the linear expansion by 3. These values are given in Table V.

TABLE V.

Metal.	Formulæ for correcting the linear expansion.
Cadmium	$L_t=L_0(1+10^{-4}\times 0{\cdot}2693t+10^{-6}\times 0{\cdot}0466t^2)$
Zinc	$L_t=L_0(1+10^{-4}\times 0{\cdot}2741t+10^{-6}\times 0{\cdot}0234t^2)$
Lead	$L_t=L_0(1+10^{-4}\times 0{\cdot}2726t+10^{-6}\times 0{\cdot}0074t^2)$
Tin	$L_t=L_0(1+10^{-4}\times 0{\cdot}2033t+10^{-6}\times 0{\cdot}0263t^2)$
Silver	$L_t=L_0(1+10^{-4}\times 0{\cdot}1809t+10^{-6}\times 0{\cdot}0135t^2)$
Copper	$L_t=L_0(1+10^{-4}\times 0{\cdot}1481t+10^{-6}\times 0{\cdot}0185t^2)$
Gold	$L_t=L_0(1+10^{-4}\times 0{\cdot}1358t+10^{-6}\times 0{\cdot}0112t^2)$
Bismuth	$L_t=L_0(1+10^{-4}\times 0{\cdot}1167t+10^{-6}\times 0{\cdot}0149t^2)$
Palladium	$L_t=L_0(1+10^{-4}\times 0{\cdot}1011t+10^{-6}\times 0{\cdot}0093t^2)$
Antimony	$L_t=L_0(1+10^{-4}\times 0{\cdot}0923t+10^{-6}\times 0{\cdot}0132t^2)$
Platinum	$L_t=L_0(1+10^{-4}\times 0{\cdot}0851t+10^{-6}\times 0{\cdot}0035t^2)$

These values agree in most instances with those found by former observers; and as these only determined the expansion between 0° and 100°, I give in the following Table the volume and length which a unit volume or length at 0° will occupy at 100° as deduced from the formulæ.

TABLE VI.

	$V_0=1$, then $V_{100}=$	$L_0=1$, then $L_{100}=$
Cadmium	1·009478	1·003159
Zinc	1·008928	1·002976
Lead	1·008399	1·002799
Tin	1·006889	1·002296
Silver	1·005831	1·001943
Copper	1·004998	1·001866
Gold	1·004411	1·001470
Bismuth	1·003948	1·001316
Palladium	1·003312	1·001104
Antimony	1·003167	1·001056
Platinum	1·002658	1·000886

---

[*] The formula here given is the mean of Series No. 1 and 2, and No. 13.

On the Expansion by Heat of Alloys.

The alloys were made in the manner described in a former paper*, and the results obtained are contained in Table VII.

I have grouped them together in the same way as I did when speaking of their electric conducting-power.

TABLE VII.

No. 24.—Sn_4Pb gilded, thrice boiled.

T.	Loss of weight in water = W.	$W(1+at)$.
12·0	7·04010	7·04345
51·5	6·97425	7·06265
95·0	6·81730	7·08610

$V_t = 7{\cdot}03801(1+10^{-4}\times 0{\cdot}6331t+10^{-6}\times 0{\cdot}0907t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}007238$.

No. 25.—Sn_4Pb gilded, once boiled.

15·0	7·03845	7·04475
59·4	6·95050	7·06620
95·1	6·81635	7·08560

$V_t = 7{\cdot}03817(1+10^{-4}\times 0{\cdot}6068t+10^{-6}\times 0{\cdot}107t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}007138$.

No. 26.—Pb_4Sn gilded, twice boiled.

11·0	5·26995	5·27190
54·8	5·21670	5·29115
95·8	5·10535	5·30965

$V_t = 5{\cdot}26715(1+10^{-4}\times 0{\cdot}8171t+10^{-6}\times 0{\cdot}0263t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008434$.

No. 27.—Pb_4Sn gilded, once boiled.

11·0	5·27395	5·27590
52·8	5·22465	5·29410
95·6	5·10975	5·31350

$V_t = 5{\cdot}27124(1+10^{-4}\times 0{\cdot}8004t+10^{-6}\times 0{\cdot}0401t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}008405$.

No. 28.—Cd Pb gilded, twice boiled.

8·6	5·36850	5·36935
56·4	5·31245	5·39260
98·1	5·19620	5·41305

$V_t = 5{\cdot}36519(1+10^{-4}\times 0{\cdot}9012t+10^{-6}\times 0{\cdot}0834t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}909095$.

No. 29.—Cd Pb gilded, once boiled.

9·2	5·60060	5·60175
60·4	5·53285	5·62790
91·7	5·44265	5·64415

$V_t = 5{\cdot}59711(1+10^{-4}\times 0{\cdot}8998t+10^{-6}\times 0{\cdot}018t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}009180$.

---

* Philosophical Transactions, 1860.

TABLE VII. (continued.)

No. 30.—Sn_4Zn gilded, once boiled.

T.	Loss of weight in water=W.	W(1+*at*).
9·3	6·58530	6·58670
54·7	6·51495	6·60765
95·9	6·37195	6·62740

$V_t=6{\cdot}58252(1+10^{-4}\times0{\cdot}6809t+10^{-6}\times0{\cdot}0314t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}007123$.

No. 31.—Sn_4Zn gilded, once boiled.

10·7	6·58830	6·59055
60·9	6·49990	6·61330
94·5	6·38165	6·63095

$V_t=6{\cdot}58626(1+10^{-4}\times0{\cdot}5945t+10^{-6}\times0{\cdot}130t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}007245$.

No. 32.—Sn_6Zn gilded, once boiled.

11·1	6·85455	6·85715
57·9	6·77180	6·87915
96·8	6·62940	6·89960

$V_t=6{\cdot}85235(1+10^{-4}\times0{\cdot}6205t+10^{-6}\times0{\cdot}0948t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}007153$.

No. 33.—Sn_6Zn gilded, thrice boiled.

14·3	7·23135	7·23705
52·7	7·16090	7·25575
91·4	7·01775	7·27610

$V_t=7{\cdot}23047(1+10^{-4}\times0{\cdot}6268t+10^{-6}\times0{\cdot}0697t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}006965$.

No. 34.—$Bi_{44}Sn$ gilded, thrice boiled.

16·2	5·49395	5·49995
53·2	5·43465	5·50795
91·1	5·32160	5·51635

$V_t=5{\cdot}49651(1+10^{-4}\times0{\cdot}3842t+10^{-6}\times0{\cdot}0132t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}003974$.

No. 35.—$Bi_{44}Sn$ gilded, once boiled.

10·8	6·10665	6·10885
57·8	6·02515	6·12040
94·0	5·90165	6·13005

$V_t=6{\cdot}10635(1+10^{-4}\times0{\cdot}3743t+10^{-6}\times0{\cdot}0410t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}004153$.

No. 36.—$BiSn_2$ gilded, once boiled.

10·2	6·04220	6·04395
58·6	5·96205	6·05875
96·8	5·83300	6·07065

$V_t=6{\cdot}04087(1+10^{-4}\times0{\cdot}4987t+10^{-6}\times0{\cdot}0110t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}005097$.

TABLE VII. (continued.)

No. 37.—$BiSn_2$ gilded, once boiled.

T.	Loss of weight in water=W.	W(1+*at*).
10·9	6·05175	6·05390
57·5	5·97470	6·06820
97·6	5·83920	6·08070

$V_t=6·05059(1+10^{-4}\times 0·5008t+10^{-6}\times 0·00925t^2)$, or if $V_0=1$, then $V_{100}=1·005100$.

No. 38.—$Bi_{24}Pb$ gilded, once boiled.

10·2	6·72710	6·72905
56·6	6·64040	6·74125
94·4	6·49825	6·75160

$V_t=6·72644(1+10^{-4}\times 0·3781t+10^{-6}\times 0·0192t^2)$, or if $V_0=1$, then $V_{100}=1·003973$.

No. 39.—$Bi_{24}Pb$ gilded, once boiled.

13·2	6·11480	6·11865
50·4	6·05440	6·12800
90·9	5·92270	6·13865

$V_t=6·11543(1+10^{-4}+0·3955t+10^{-6}\times 0·0245t^2)$, or if $V_0=1$, then $V_{100}=1·004200$.

No. 40.—$BiPb_2$ gilded, once boiled.

11·1	5·97110	5·97335
56·5	5·90675	5·99615
96·8	5·78095	6·01655

$V_t=5·96780(1+10^{-4}\times 0·8362t+10^{-6}\times 0·00782t^2)$, or if $V_0=1$, then $V_{100}=1·008440$.

No. 41.—$BiPb_2$ gilded, once boiled.

10·6	6·17070	6·17275
53·1	6·11340	6·19555
95·0	5·98260	6·21850

$V_t=6·16714(1+10^{-4}\times 0·8561t+10^{-6}\times 0·0216t^2)$, or if $V_0=1$, then $V_{100}=1·008777$.

No. 42.—$BiPb_2$, gilded, once boiled.

12·4	5·17255	5·17520
58·1	5·11390	5·19550
96·8	5·00855	5·21300

$V_t=5·16976(1+10^{-4}\times 0·8463+10^{-6}\times 0·0183t^2)$, or if $V_0=1$, then $V_{100}=1·008646$.

No. 43.—Alloy of copper and zinc, containing 71·0 per cent. by weight copper, determined by analysis, gilded, thrice boiled.

9·8	7·61120	7·61315
57·4	7·51595	7·63315
97·1	7·35020	7·65145

$V_t=7·60930(1+10^{-4}\times 0·5109t+10^{-6}\times 0·0614t^2)$, or if $V_0=1$, then $V_{100}=1·005723$.

TABLE VII. (continued.)

No. 44.—No. 43 repeated.

T.	Loss of weight in water=W.	$W(1+at)$.	Calculated.
11·2	7·61090	7·61385	
58·9	7·51100	7·63405	
96·5	7·35315	7·65120	

$V_t=7{\cdot}60936(1+10^{-4}\times 0{\cdot}5213t+10^{-6}\times 0{\cdot}0503t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}005716$.

No. 45.—Au Sn_2, thrice boiled.

9·8	5·24965	5·25100	
51·6	5·19420	5·26025	
97·4	5·06210	5·27070	

$V_t=5{\cdot}2487(1+10^{-4}\times 0{\cdot}4124t+10^{-6}\times 0{\cdot}0149t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}004273$.

No. 46.—Au Sn_2, twice boiled.

10·5	5·44040	5·44215	
55·7	5·37295	5·45210	
97·1	5·24700	5·46205	

$V_t=5{\cdot}43997(1+10^{-4}\times 0{\cdot}3763t+10^{-6}\times 0{\cdot}0429t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}004192$.

No. 47.—Au_2 Sn, twice boiled.

12·0	5·57075	5·57340	
55·1	5·50440	5·58380	
96·8	5·37535	5·59445	

$V_t=5{\cdot}57061(1+10^{-4}\times 0{\cdot}4132t+10^{-6}\times 0{\cdot}0298t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}004430$.

No. 48.—Au_2 Sn_7, gilded, twice boiled.

12·1	5·58500	5·58775	
56·3	5·51560	5·59850	
95·3	5·39450	5·60840	

$V_t=5{\cdot}58489(1+10^{-4}\times 0{\cdot}4198t+10^{-6}\times 0{\cdot}0229t^2)$, or if $V_0=1$, then $V_{100}=1{\cdot}004427$.

No. 49.—Ag_4 Au, thrice boiled.

9·7	3·64395	3·64485	3·64485
51·4	3·60725	3·65270	3·65270
96·1	3·51950	3·66110	3·66110

$V_t=3{\cdot}64303(1+10^{-4}\times 0{\cdot}5163t)$, or if $V_0=1$, then $V_{100}=1{\cdot}005163$.

No. 50.—Ag_4 Au, thrice boiled.

10·8	3·76475	3·76605	3·76604
58·5	3·71525	3·77530	3·77532
92·8	3·64415	3·78200	3·78200

$V_t=3{\cdot}76394(1+10^{-4}\times 0{\cdot}5170t)$, or if $V_0=1$, then $V_{100}=1{\cdot}005170$.

TABLE VII. (continued.)

No. 51.—Ag Au, thrice boiled.

T.	Loss of weight in water = W.	W(1 + *at*).	Calculated.
8·6	3·99445	3·99510	3·99510
57·3	3·94340	4·00470	4·00465
98·4	3·85115	4·01270	4·01270

$V_t = 3{\cdot}99342(1 + 10^{-4} \times 0{\cdot}4906t)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004906$.

No. 52.—Ag Au, thrice boiled.

9·0	3·99005	3·99080	3·99080
58·3	3·93730	4·00055	4·00055
98·0	3·84800	4·00830	4·00831

$V_t = 3{\cdot}98904(1 + 10^{-4} \times 0{\cdot}4927t)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004927$.

No. 53.—Ag Au_4, thrice boiled.

9·6	2·90470	2·90540
60·6	2·86165	2·91110
94·1	2·80700	2·91585

$V_t = 2{\cdot}90453(1 + 10^{-4} \times 0{\cdot}2989t + 10^{-6} \times 0{\cdot}123t^2)$, or if $V_0 1$, then $V_{100} = 1{\cdot}004119$.

No. 54.—Ag Au_4, thrice boiled.

8·4	2·98805	2·98850
56·7	2·94930	2·99425
93·5	2·88895	2·99970

$V_t = 2{\cdot}98766(1 + 10^{-4} \times 0{\cdot}3241t + 10^{-6} \times 0{\cdot}114t^2)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004381$.

No. 55.—Alloy of silver and platinum, containing 66·6 per cent. by weight silver (lent by Messrs. JOHNSON and MATTHEY), thrice boiled.

7·0	4·67260	4·67290
58·4	4·60940	4·68370
96·3	4·50995	4·69200

$V_t = 4{\cdot}67147(1 + 10^{-4} \times 0{\cdot}4359t + 10^{-6} \times 0{\cdot}0213t^2)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004572$.

No. 56.—No. 55 repeated, thrice boiled.

9·4	4·67330	4·67435
59·4	4·60800	4·68470
96·8	4·50930	4·69310

$V_t = 4{\cdot}67252(1 + 10^{-4} \times 0{\cdot}4134t + 10^{-6} \times 0{\cdot}0431t^2)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004565$.

No. 57.—Alloy of gold and copper, containing 66·6 per cent. gold, gilded, once boiled.

11·0	4·52820	4·52985
59·4	4·46525	4·53965
97·7	4·36740	4·54835

$V_t = 4{\cdot}52781(1 + 10^{-4} \times 0{\cdot}4029 + 10^{-6} \times 0{\cdot}0629t^2)$, or if $V_0 = 1$, then $V_{100} = 1{\cdot}004658$.

TABLE VII. (continued.)

No. 58.—No. 57 repeated, twice boiled.

T.	Loss of weight in water=W.	W(1+at).
10·0	4·52845	4·52965
54·2	4·47595	4·53850
96·9	4·36970	4·54815

$V_t=4·52781(1+10^{-4}\times 0·4002t+10^{-6}\times 0·0655t^2)$, or if $V_0=1$, then $V_{100}=1·004657$.

No. 59.—Alloy of silver and copper, containing 36·1 per cent. by weight, silver determined by analysis, thrice boiled.

8·5	3·19535	3·19585
52·5	3·16165	3·20325
95·1	3·08880	3·21080

$V_t=3·19447(1+10^{-4}\times 0·5065t+10^{-6}\times 0·327t^2)$, or if $V_0=1$, then $V_{100}=1·005392$.

No. 60.—No. 59 repeated, thrice boiled.

9·6	3·19525	3·19600
56·4	3·15620	3·20380
96·0	3·08725	3·21125

$V_t=3·19454(1+10^{-4}\times 0·4704t+10^{-6}\times 0·778t^2)$, or if $V_0=1$, then $V_{100}=1·005482$.

No. 61.—Alloy of silver and copper, containing 71·6 per cent. by weight, silver determined by analysis, gilded, thrice boiled.

7·0	5·85330	5·85370
53·1	5·78990	5·86770
97·4	5·65130	5·88415

$V_t=5·85185(1+10^{-4}\times 0·4421+10^{-6}\times 0·128t^2)$, or if $V_0=1$, then $V_{100}=1·00570$.

No. 62.—No. 61 repeated, regilded, once boiled.

10·1	5·85335	5·85500
52·4	5·79205	5·86795
98·1	5·64930	5·88505

$V_t=5·85232(1+10^{-4}\times 0·4406t+10^{-6}\times 0·132t^2)$, or if $V_0=1$, then $V_{100}=1·005726$.

The alloys No. 24 to 33 belong to the first group, namely, those made of the metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes; from 34 to 48 to the third group, namely, those made of the metals which when alloyed with one another, or with one of those belonging to the first group of metals and alloys (these form the second group No. 49 to 62), conduct electricity in a lower degree than that calculated from the mean of their volumes.

In Table VIII. the mean formulæ are given for the correction of expansion by heat for the foregoing alloys; in Table IX. those for the correction of the linear expansion by heat.

TABLE VIII.

Alloy.	Mean correction formulæ for cubical expansion by heat.
Sn$_4$ Pb	$V_t=V_0(1+10^{-4}\times 0{\cdot}6200t+10^{-6}\times 0{\cdot}0988t^2)$
Pb$_4$ Sn	$V_t=V_0(1+10^{-4}\times 0{\cdot}8087t+10^{-6}\times 0{\cdot}0332t^2)$
Cd Pb	$V_t=V_0(1+10^{-4}\times 0{\cdot}9005t+10^{-6}\times 0{\cdot}0133t^2)$
Sn$_4$ Zn	$V_t=V_0(1+10^{-4}\times 0{\cdot}6377t+10^{-6}\times 0{\cdot}0807t^2)$
Sn$_6$ Zn	$V_t=V_0(1+10^{-4}\times 0{\cdot}6236t+10^{-6}\times 0{\cdot}0822t^2)$
Bi$_{44}$ Sn	$V_t=V_0(1+10^{-4}\times 0{\cdot}3793t+10^{-6}\times 0{\cdot}0271t^2)$
Bi Sn$_2$	$V_t=V_0(1+10^{-4}\times 0{\cdot}4997t+10^{-6}\times 0{\cdot}0101t^2)$
Bi$_{24}$ Pb	$V_t=V_0(1+10^{-4}\times 0{\cdot}3868t+10^{-6}\times 0{\cdot}0218t^2;$
Bi Pb$_2$	$V_t=V_0(1+10^{-4}\times 0{\cdot}8462t+10^{-6}\times 0{\cdot}0159t^2)$
Cu+Zn (71 per cent. Cu)	$V_t=V_0(1+10^{-4}\times 0{\cdot}5161t+10^{-6}\times 0{\cdot}0558t^2)$
Au Sn$_2$	$V_t=V_0(1+10^{-4}\times 0{\cdot}3944t+10^{-6}\times 0{\cdot}0289t^2)$
Au$_2$ Sn$_7$	$V_t=V_0(1+10^{-4}\times 0{\cdot}4165t+10^{-6}\times 0{\cdot}0263t^2)$
Ag$_4$ Au	$V_t=V_0(1+10^{-4}\times 0{\cdot}5166t)$
Ag Au	$V_t=V_0(1+10^{-4}\times 0{\cdot}4916t)$
Ag Au$_4$	$V_t=V_0(1+10^{-4}\times 0{\cdot}3115t+10^{-6}\times 0{\cdot}1185t^2)$
Ag+Pt (66·6 per cent. Ag)	$V_t=V_0(1+10^{-4}\times 0{\cdot}4246t+10^{-6}\times 0{\cdot}0322t^2)$
Au+Cu (66·6 per cent. Au)	$V_t=V_0(1+10^{-4}\times 0{\cdot}4015t+10^{-6}\times 0{\cdot}0642t^2)$
Ag+Cu (36·1 per cent. Ag)	$V_t=V_0(1+10^{-4}\times 0{\cdot}4884t+10^{-6}\times 0{\cdot}0552t^2)$
Ag+Cu (71·6 per cent. Ag)	$V_t=V_0(1+10^{-4}\times 0{\cdot}4413t+10^{-6}\times 0{\cdot}130t^2)$

TABLE IX.

Alloy.	Correction formulæ for linear expansion by heat.
Sn$_4$ Pb	$L_t=L_0(1+10^{-4}\times 0{\cdot}2066t+10^{-6}\times 0{\cdot}0329t^2)$
Pb$_4$ Sn	$L_t=L_0(1+10^{-4}\times 0{\cdot}2696t+10^{-6}\times 0{\cdot}0111t^2)$
Cd Pb	$L_t=L_0(1+10^{-4}\times 0{\cdot}3002t+10^{-6}\times 0{\cdot}0044t^2)$
Sn$_4$ Zn	$L_t=L_0(1+10^{-4}\times 0{\cdot}2126t+10^{-6}\times 0{\cdot}0269t^2)$
Sn$_6$ Zn	$L_t=L_0(1+10^{-4}\times 0{\cdot}2079t+10^{-6}\times 0{\cdot}0274t^2)$
Bi$_{41}$ Sn.	$L_t=L_0(1+10^{-4}\times 0{\cdot}1264t+10^{-6}\times 0{\cdot}0090t^2)$
Bi Sn$_2$	$L_t=L_0(1+10^{-4}\times 0{\cdot}1666t+10^{-6}\times 0{\cdot}0034t^2)$
Bi$_{24}$ Pb	$L_t=L_0(1+10^{-4}\times 0{\cdot}1293t+10^{-6}\times 0{\cdot}0073t^2)$
Bi Pb$_2$	$L_t=L_0(1+10^{-4}\times 0{\cdot}2821t+10^{-6}\times 0{\cdot}0053t^2)$
Cu+Zn(71 per cent. Cu)	$L_t=L_0(1+10^{-4}\times 0{\cdot}1720t+10^{-6}\times 0{\cdot}0186t^2)$
Au Sn$_2$	$L_t=L_0(1+10^{-4}\times 0{\cdot}1315t+10^{-6}\times 0{\cdot}0096t^2)$
Au$_2$ Sn	$L_t=L_0(1+10^{-4}\times 0{\cdot}1388t+10^{-6}\times 0{\cdot}0088t^2)$
Ag Au	$L_t=L_0(1+10^{-4}\times 0{\cdot}1722t)$
Ag Au$_4$	$L_t=L_0(1+10^{-4}\times 0{\cdot}1638t)$
Ag Au$_4$	$L_t=L_0(1+10^{-4}\times 0{\cdot}1038t+10^{-6}\times 0{\cdot}0395t^2)$
Ag+Pt (66·6 per cent. Pt)	$L_t=L_0(1+10^{-4}\times 0{\cdot}1415t+10^{-6}\times 0{\cdot}0107t^2)$
Au+Cu (66·6 per cent. Au)	$L_t=L_0(1+10^{-4}\times 0{\cdot}1338t+10^{-6}\times 0{\cdot}0214t^2)$
Ag+Cu (31·6 per cent. Ag)	$L_t=L_0(1+10^{-4}\times 0{\cdot}1628t+10^{-6}\times 0{\cdot}0182t^2)$
Ag+Cu (76·1 per cent. Ag)	$L_t=L_0(1+10^{-4}\times 0{\cdot}1471t+10^{-6}\times 0{\cdot}0433t^2)$

In Table X. the observed and the calculated cubical expansion by heat, between 0° and 100°, of the above alloys are given. The calculations are based on the assumption that the coefficient of expansion of an alloy is equal to the mean of the coefficients of the component metals (expressed in volumes).

TABLE X.

	Vol. per cent.	Observed vol. at 0°=1, then vol. at 100°=	Calculated vol. at 0°=1, then vol. at 100°=
Sn_4 Pb	22·28 of Pb	1·007188	1·007225
Pb_4 Sn	82·09 of Pb	1·008419	1·008128
Cd Pb	58·49 of Pb	1·009138	1·008847
Sn_4 Zn	87·46 of Sn	1·007184	1·007144
Sn_6 Zn	91·28 of Sn	1·007058	1·007066
Bi_{44} Sn	0·85 of Sn	1·004064	1·003972
Bi Sn_2	42·81 of Sn	1·005098	1·005207
Bi_{24} Pb	1·76 of Pb	1·004086	1·004026
Bi Pb_2	46·26 of Pb	1·008621	1·006007
Cu+Zn (71 per cent. Cu).	33·85 of Zn	1·005719	1·006328
Au Sn_2	60·85 of Sn	1·004233	1·005919
Au_2 Sn_7	73·14 of Sn	1·004428	1·006223
Ag_4 Au	19·86 of Au	1·005166	1·005549
Ag Au	49·79 of Au	1·004916	1·005123
Ag Au_4	79·86 of Au	1·004300	1·004693
Ag+Pt (66·6 per cent. Ag)	19·65 of Pt	1·004568	1·005207
Au+Cu (66·6 per cent. Au)	48·06 of Au	1·004657	1·004716
Ag+Cu (36·1 per cent. Ag)	28·31 of Ag	1·005436	1·00533
Ag+Cu (71·6 per cent. Ag)	71·13 of Ag	1·005713	1·00507.

In Table XI. the equivalents and specific gravities used for the foregoing calculations are given.

TABLE XI.

Metal.	Equivalent.	Specific gravity.
Cadmium	56·0	8·655
Zinc	32·6	7·148
Lead	103·7	11·376
Tin	58·0	7·294
Silver	108·0	10·468
Copper	31·7	8·950
Gold	197·0	19·265
Bismuth	208·0	9·822
Platinum	——	21·400

On comparing the observed with the calculated volumes, we find that they mostly agree together as well as may be expected, considering that the observed values cannot be deemed absolutely correct, and that a difference in the crystalline form will in all probability cause a slight difference in the coefficients of expansion. It is well known that alloys crystallize much more readily, in most cases, than the component metals, and not always in the same form. The difference between the observed and calculated values obtained for the alloy Bi Pb_2 is so great that I thought some error had occurred in making the alloy; I therefore remade it, redetermined the coefficient of expansion (Series No. 42), and obtained the same values. That the gold-tin alloys have lower coefficients of expansion than those of the mean of the component volumes of the metals forming them is not surprising, as in all probability there exist chemical combinations between the two metals,—just as it may be said *that the specific gravity of an alloy is approximately equal to the mean specific gravities of the volumes of the component metals*, so also from the foregoing we may deduce *that the volume which an alloy will occupy at any temperature between* 0° *and* 100° *is approximately equal to the mean of the component volumes of the metals at the same temperature*, or, in other words, *the cubical or linear coefficients of expansion by heat of an alloy between* 0° *and* 100° *are approximately equal to the mean cubical or linear coefficients of expansion by heat of the component metals.*

In Table XII. I have given the values from Table X., together with the observed and calculated specific gravities and conducting-powers of the alloys experimented with.

Table XII.

	Vol. 0=1, then vol. 100=		Specific gravity.		Conducting-power.	
	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.
$Sn_4 Pb$ . . .	1·007188	1·007225	8·818	8·203	10·57	10·63
$Pb\ Sn$ . . .	1·008419	1·008129	10·590	10·645	8·28	8·43
$Cd\ Pb$ . . .	1·009138	1·008847	10·246	10·246	12·61	13·72
$Sn_4 Zn$ . . .	1·007184	1·007144	……	……	13·22	13·45
$Sn_6 Zn$ . . .	1·007058	1·007066	……	……	12·66	12·84
$Bi_{44} Sn$ . . .	1·004064	1·003972	9·803	9·801	0·245	1·28
$Bi\ Sn_2$ . . .	1·005098	1·005207	8·772	8·738	3·96	5·59
$Bi_{24} Pb$ . . .	1·004086	1·004026	9·845	9·850	0·257	1·30
$Bi\ Pb_3$ . .	1·008621	1·006007	10·956	10·541	2·09	4·23
Cu+Zn . . (33·85 vol. Zn)	1·005719	1·006328	……	……	21·70	70·20
$Au\ Sn_3$ . .	1·004233	1·005919	11·833	11·978	14·27	35·51
$Au_2 Sn_7$ . .	1·004428	1·006223	……	……	6·00	28·25
$Ag_4 Au$ . .	1·005166	1·005549	12·257	12·215	20·91	94·62
$Ag\ Au$ . .	1·004916	1·005123	14·870	14·847	14·59	86·52
$Ag\ Au_4$ . .	1·004300	1·004693	17·540	17·493	20·91	78·38
Ag+Pt . . (19·65 vol. Pt)	1·004568	1·004693	……	……	6·70	83·60
Au+Cu . . (48·06 vol. Au)	1·004657	1·004716	……	……	12·00	83·25
Ag+Cu . . (28 31 vol. Ag)	1·005436	1·005233	……	……	67·85	95·00
Ag+Cu . . (73·13 vol. Ag)	1·005713	1·005607	……	……	63·00	98·20

The specific gravities of some of the alloys are not given, as they were not determined with the others. Their values deduced, with the help of the data given in this paper, would not be correct, as for the present research the castings were made more with the idea of producing a perfect surface than an absolute solid; no doubt many of them had internal cavities owing to the surface being rapidly cooled, and for this reason I have not given the absolute weights of the metals or the alloys.

It is worth remarking that the observed specific gravity of the alloy $Bi\,Pb_2$ differs considerably from the calculated one.

From the conclusions just drawn it would appear that the determinations of the expansion by heat of alloys give in general no indication as to their chemical nature, and that this property belongs to that class of physical properties which does not indicate their chemical nature. In the Report on the Chemical Nature of Alloys*, I have shown that, from the determinations of the electric conducting-power of alloys, we may gain an insight into their chemical nature; and basing my calculations on the hypothesis there propounded, I am at present able to deduce the conducting-power of any alloy which may be considered as a solidified solution of the one metal in the other, although it may differ widely from that calculated from the mean conducting-power of the component metals, as shown in Table XII.

It is proper to point out that the coefficients given in Tables IV., V., VIII., and IX., are those calculated from readings of the ordinary mercury-thermometer, the mercury being contained in a tube of glass. Therefore, except at the two values 0° and 100°, the temperatures indicated by the degrees of the thermometer I used will differ—

I. From the temperature corresponding to the same number of degrees of an air-thermometer.

II. From the temperature corresponding to the same number of degrees of a mercurial thermometer, the mercury being contained in a tube of some substance absolutely unaffected as to its volume by heat, could such be found.

The proper corrections can be deduced from the following Table:—

Temperatures indicated by air-thermometer.	Temperatures indicated by ordinary thermometer at same time.
10°·0	10°·08
20·0	20·14
30·0	30·18
40·0	40·20
50·0	50·20
60·0	60·18
70·0	70·14
80·0	80·10
90·0	90·05
100·0	100·00

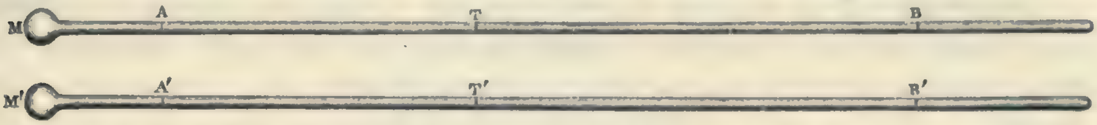
This Table is copied from RECKNAGEL.

REGNAULT found 50° air-thermometer to correspond to 50°·20 by mercurial thermometer.

Professor MILLER has sent me the following investigation of the correction to be applied to reduce the temperatures indicated by the common mercurial thermometer to those indicated by a thermometer of the second kind mentioned above. I have since found that RECKNAGEL[*] and POGGENDORFF[†] have given a similar investigation.

---

* British Association Report, 1863.



Let M B denote a mercurial thermometer in which A is the freezing-, B the boiling-point, the capacity of the tube between A and B being divided into 100 parts of equal capacity.

Let M′ B′ denote a thermometer of material absolutely uninfluenced by heat, having exactly the dimensions of A B when at 0° C; A′, B′ its freezing- and boiling-points, and the capacity of A′, B′ divided into 100 parts of equal volume.

Let V be the capacity of M A at 0°, 100 K the capacity of A B at 0°. Since the thermometers are exactly alike at 0°, the capacity of M′ A′ will be V. Let the capacity of $A'B'=100\,mV$, and, therefore, m the cubic expansion of mercury for 1° in terms of the indications of thermometer M′ B′; g the cubic expansion of glass for 1°.

When the thermometers are at the same temperature, let the ends of the columns of mercury stand at T, T′, t, t' being the number of degrees between A and T, and A′ and T′ respectively.

The capacity of M A will now be $V(1+gt')$, and that of A T will be $Kt\,(1+gt')$, and the volume of the mercury in M T will be $V(1+mt')$. Hence

$$V(1+mt')=V(1+gt')+Kt(1+gt').$$

Therefore

$$V(m-g)t'=Kt(1+gt').$$

But t and t' are both 100 at the same time. Hence

$$V(m-g)100=K100(1+g100).$$

Therefore

$$t'=t\frac{1+gt'}{1+g100}=t-gt(100-t')\text{ very nearly.}$$

But g is very small and t' very nearly equal to t. Hence

$$t'=t-gt(100-t)\text{ very nearly.}$$

g varies from 0·000023 to 0·000028. Taking the higher value,

$$\text{at }50^\circ\text{ C., }t-t'=0{\cdot}000028\times50\times50=0^\circ{\cdot}07\text{ C.,}$$
$$\text{at }25^\circ\text{ C., }t-t'=0{\cdot}000028\times25\times75=0^\circ{\cdot}052\text{ C.}$$

Hence the expansion of mercury is not proportional to its ascent in the tube of a thermometer, and the difference of rates is a perfectly sensible quantity, too large to neglect in many researches. Part of the increased rate of expansion of various bodies at high temperatures is due to this error of the mercurial thermometer, which indicates temperature between 0° and 100° too high as measured by the true expansion of mercury.

---

[*] POGGENDORFF's 'Annalen,' vol. cxxiii. p. 115.

[†] Ibid. vol. xli. p. 372.

Regnault frequently used a thermomètre à poids. Let P be the weight of mercury contained in it at 0° C., p the weight of mercury expelled when exposed to the temperature t by ordinary thermometer.

At temperature t by ordinary thermometer the volume of mercury below 0° is $V(1+gt')$, and the volume of the mercury above 0° is $Kt(1+gt')$. Therefore the volume of the whole of the mercury is $V(1+gt')+Kt(1+gt')$.

Hence

$$\frac{p}{P}=\frac{Kt(1+gt')}{V(1+gt')+Kt(1+gt')}=\frac{Kt}{V+Kt}.$$

Therefore

$$\frac{p}{P-p}=\frac{Kt}{V}.\quad \text{When } t=100 \text{ let } p=b.$$

Therefore

$$\frac{b}{P-b}=\frac{K\,100}{V};$$

therefore

$$\frac{t}{100}=\frac{P-b}{P-p}\,\frac{P}{b}.$$

Regnault uses $\frac{P-b}{P-p}\,\frac{p}{b}$ as the measure of temperature, which is the same as $\frac{t}{100}$, the indication of a common mercurial thermometer uncorrected for the effect produced by the expansion of glass.

A small error is generally made in taking the boiling-point of water, 100°, viz. the influence of latitude is not taken into consideration. Professor **Miller** writes to me on this point the following:—"**Laplace**, in the fifth edition of his 'Système du Monde,' states that he regards 100° C. to mean the temperature of water boiling under a pressure equivalent to that of a column of mercury at 0° and 760 millims. in latitude 45°.

"**Dulong**, and afterwards **Regnault**, assumed 100° to be that of boiling water under normal pressure at Paris. Now the pressure at 760 millims. of mercury at the level of the sea in latitude 45° is equivalent to a column in latitude λ at z metres above the level of the sea, the height of which is $760\left(1-1{\cdot}32\frac{z}{r}\right)(1-0{\cdot}0025659\cos.2\lambda)$, where $r=$ radius of the earth $=6366198$ metres.

"The latitude of Paris (48° 50′ 14″) is not very different from 45°. **Regnault's** place of observation was about 60 metres above the sea. Hence a column of 760 millims. mercury at the level of the sea exerts the same pressure as a column of 759·75 millims. in **Regnault's** laboratory."

This will only make a difference in the boiling-point of 0·01, a difference which may be neglected in ordinary work, but in normal researches ought to be brought into calculation; as, for example, in **Miller's** normal research "On the Construction of the New Standard Pound"*. At Åbo this correction would amount to upwards of 0°·25.

In the text-books on chemistry and natural philosophy we find the coefficients of expansion of air given 0·003665 for each degree of the mercury-thermometer, which is not correct; for as air expands regularly between 0° and 100° according to the air-thermometer, a unit of volume of air measured at 0° will not occupy a volume at 20·14 mercury-thermometer equal to

---

* Philosophical Transactions, 1856, p. 753.

$$1+0{\cdot}003665\times 20{\cdot}14=1{\cdot}07380,$$

but

$$1+0{\cdot}003665\times 20=1{\cdot}07330,$$

showing a difference of 0·05 per cent.

Miller, in his paper already mentioned, p. 714, says, "Regnault found the expansion of air from 0° to 100° under constant pressure equal to 0·36706 of its volume at 0°.... The difference between the mercurial and air-thermometers amounts to about 0·2. Hence the expansion of air between 0° and 50°·2 is 0·18353 of its volume at 0°; or between 0° and 50° the ratio of the density of air at 0° to its density at t is $1+0{\cdot}003656\times t$."

In the present state of science it seems quite wrong that such a want of accordance should exist in our normal instruments, considering that otherwise the errors that exist between the instruments do not amount to 0°·1 when properly made. I have had several normal thermometers made for my experiments by Messrs. Negretti and Zambra, and in every case, when compared with my Kew Standard, the agreement between them has been almost perfect.

It would be decidedly a step in the right direction if in future the fact that mercury does not expand regularly between 0° and 100° were taken into account in the construction of all normal thermometers; and if some comparisons between the Kew Standard and the air-thermometer were made, then the readings of thermometers which have been compared with the Kew Standard might be easily corrected.

Jolly[*], in his research into the expansion of water, corrected his thermometers by comparing them with an air-thermometer; unfortunately, however, he does not give a table containing these comparisons; so that his results are obviously not comparable with those obtained with the mercury-thermometer, and therefore at present I am unable to compare his results with those obtained on the same subject by myself. In conclusion, my thanks are due to Dr. M. Behrend for carrying out the determinations for the Series 1, 2, 13, 20, 21, 24 to 27 and 34, to Mr. Bassett, who aided me in carrying out the others, and to Mr. R. P. Wright for having undertaken the greater part of the computations.

---

[*] Berichte der K. b. Akad. der Wissench. zu München, 1864, p. 141.

INDEX

TO THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1866.

A.

Abel (F. A.). Researches on Gun-cotton.—On the Manufacture and Composition of Gun-cotton, 269.

Acetic ether, synthesis of ethers from, 37; preparation of, 37 (see **Frankland**).

Antedon, development, &c. of, 671 (see **Carpenter**).

B.

Bakerian Lecture.—On the Viscosity or Internal Friction of Air and other Gases, 249 (see **Maxwell**).

Bastian (H. C.). On the Anatomy and Physiology of the Nematoids, Parasitic and Free; with observations on their Zoological Position and Affinities to the Echinoderms, 545 (for Contents see p. 545).

Brodie (Sir B. C.). The Calculus of Chemical Operations; being a Method for the Investigation, by means of Symbols, of the Laws of Distribution of Weight in Chemical Change.—Part I. On the Construction of Chemical Symbols, 781 (for Contents see p. 781).

C.

Calorescence, 1.

Carpenter (W. B.). Researches on the Structure, Physiology, and Development of *Antedon* (*Comatula,* Lamk.) *rosaceus.*—Part I., 671 (for Contents see p. 671).

Cayley (A.). A Supplementary Memoir on the Theory of Matrices, 25.

————. Addition to the Memoir on **Tschirnhausen**'s Transformation, 97.

Chameleon's retina, 223 (see **Hulke**).

Chemical change, connexion between the conditions of, and its amount, 193 (see **Harcourt**).

Chemical operations, calculus of, 781 (see **Brodie**).

Comatula, development &c. of, 671 (see **Carpenter**).

Contrafocal ellipsoids, 760.

D.

Dialysis of gases, 399 (see GRAHAM).

DUPPA (B. F.) and FRANKLAND (E.). Researches on Acids of the Lactic Series, 309 (see FRANKLAND).

———————————. Synthetical Researches on Ethers, 37 (see FRANKLAND).

E.

Elasticity, determination of the two constants of, for an isotropic solid, 185 (see EVERETT).

ESSON (W.). A Theoretical Discussion of some cases of Chemical Change, 216.

ESSON (W.) and HARCOURT (A. V.). On the Laws of Connexion between the Conditions of a Chemical Change and its Amount, 193 (see HARCOURT).

Ethers, synthetical researches on, 37; constitution, &c., of certain, 59 (see FRANKLAND).

EVERETT (J. D.). Account of Experiments on the Flexural and Torsional Rigidity of a Glass Rod, leading to the Determination of the Rigidity of Glass, 185.

Expansion by heat of water and mercury, 231; of metals and alloys, 861.

F.

Fatty acids, constitution of the, 68 (see FRANKLAND).

FOX (W.). On the Development of Striated Muscular Fibre, 101.

FRANKLAND (E.) and DUPPA (B. F.). Researches on Acids of the Lactic Series.—No. I. Synthesis of Acids of the Lactic Series, 309.

———————————. Synthetical Researches on Ethers.—No. I. Synthesis of Ethers from Acetic Ether, 37.—Action of sodium and ethyl iodide upon acetic ether, and examination of the products, 37; constitution and chemical relations of the ethers and ketones derived from the duplication of the atom of acetic ether, 59; constitution of the fatty acids, 68.

G.

Gases, viscosity of, 249 (see MAXWELL); dialytic separation of, by colloid septa, 399 (see GRAHAM).

GRAHAM (T.). On the Absorption and Dialytic Separation of Gases by Colloid Septa, 399.—Part I. Action of a septum of caoutchouc, 399.—Part II. Action of metallic septa at a red heat, 415.

Gun-cotton, manufacture and composition of, 269.

Gyrometer, liquid, and gyrometric governor, 661 (see SIEMENS).

H.

HARCOURT (A. V.) and ESSON (W.). On the Laws of Connexion between the Conditions of a Chemical Change and its Amount, 193.—On the reaction of permanganic and oxalic acids, 193; Appendix, containing a theoretical discussion of some cases of chemical change, 216.

HAUGHTON (S.). On the Tides of the Arctic Seas.—Part III. On the Semidiurnal Tides of Frederiksdal, near Cape Farewell in Greenland, 639.—Appendix to Part II. On the semidiurnal tides of Port Leopold, North Somerset, 654.

Heat, incandescence produced by invisible radiant, 11; influence of colour and mechanical condition on radiant, 83.

HUGGINS (W.). Further Observations on some of the Nebulæ, with a Mode of determining the Brightness of these Bodies, 381.

HULKE (J. W.). On the Chameleon's Retina; a further Contribution to the Minute Anatomy of the Retina of Reptiles, 223.

K.

Ketones, constitution, &c., of certain, 59 (see FRANKLAND).

L.

Lactic acid series, 309 (see FRANKLAND).

Lunar-diurnal variation of magnetic elements, 441 (see SABINE).

M.

Magnetic observations, discussion of, 441, 453 (see SABINE).

Matrices, theory of, 25.

MATTHIESSEN (A.) On the Expansion by Heat of Water and Mercury, 231.

——————— On the Expansion by Heat of Metals and Alloys, 861.

MAXWELL (J. C.). THE BAKERIAN LECTURE.—On the Viscosity or Internal Friction of Air and other Gases, 249. Postscript, 267.

Mechanics, fundamental views regarding, 361.

Moon, mass of, deduced from the tides, 642, 655.

Muscular fibre, development of striated, 101.

N.

Nebulæ, observations on, 381; mode of determining the brightness of, 392.

Nematoids, anatomy and physiology of, 545 (see BASTIAN).

O.

Ostrich Tribe, structure and development of the skull in the, 113 (see PARKER).

OWEN (R.). On the Fossil Mammals of Australia.—Part II. Description of an almost entire Skull of *Thylacoleo carnifex*, OWEN, from a freshwater deposit, Darling Downs, Queensland, 73.

Oxatyl, 342.

P.

PARKER (W. K.). On the Structure and Development of the Skull in the Ostrich Tribe, 113.—Introduction, 113; skull of Struthio, 114; Rhea, 128; Dromæus, 135; Casuarius, 152; Dinornis, 163; Palapteryx, 170; Apteryx, 171; Tinamus, 174; Description of the Plates, 179.

PLÜCKER (J.). Fundamental Views regarding Mechanics, 361.

POINSOT's *mode of representing the rotatory motion of a free rigid body*, deduction of, 767.

R.

Radiation of heat, 1, 83 (see TYNDALL).
Retina of reptiles, 223 (see HULKE).
ROSS (Sir J. C.), discussion of Magnetic Observations made under the direction of, 453 (see SABINE).
Rotation of a free rigid body, 757, 767.

S.

SABINE (E.). Results of the Magnetic Observations at the Kew Observatory, No. III.—§ 9. Lunar-diurnal variation of the three magnetic elements, 441.
——— Contributions to Terrestrial Magnetism, No. X., 453.
Sea, depth of, deduced from the tides, 642, 655.
SIEMENS (C. W.). On Uniform Rotation, 657.
Spectra of nebulæ, 381.
SYLVESTER (J. J.). On the Motion of a Rigid Body acted on by no external Forces, 757.

T.

Thylacoleo carnifex, 73 (see OWEN).
Tides of the Arctic Seas, 639 (see HAUGHTON).
TSCHIRNHAUSEN'S *Transformation*, 97.
TYNDALL (J.). Sixth Memoir on Radiation and Absorption.—Influence of Colour and Mechanical Condition on Radiant Heat, 83.
——— On Calorescence, 1.

V.

Viscosity of air, &c., 249 (see MAXWELL).

LONDON:
PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

PRESENTS

RECEIVED BY

THE ROYAL SOCIETY,

WITH THE

NAMES OF THE DONORS.

From November 1865 to June 1866.

Presents.	Donors.
ABBADIE (A. d') Rapport sur la Planchette Photographique de M. Auguste Chevallier. 8vo. *Paris* 1862.	The Author.
ABEL (John) Memorials of Queen Eleanor, illustrated by Photography, with a short Account of their History and present condition. fol. *London* 1864.	The Author.
ACADEMIES and SOCIETIES.	
Amiens:—Congrès Scientifique de France. 33ᵉ Session. 4to. *Amiens* 1866.	The Congress.
Amsterdam:—	
Verhandelingen der Koninklijke Akademie van Wetenschappen. Deel X. 4to. *Amsterdam* 1864.	The Academy.
Verhandelingen. Afdeeling Letterkunde. Deel III. 4to. *Amsterdam* 1865.	———
Verslagen en Mededeelingen. Afdeeling Natuurkunde. Deel XVII. 8vo. *Amsterdam* 1865.	———
——— ——— Afdeeling Letterkunde. Deel VIII. 8vo. *Amsterdam* 1865.	———
Jaarboek, 1863, 1864. 8vo. *Amsterdam.*	———
Carmina Latina. 8vo. *Amsterdam* 1864.	———
Musée Vrolik: Catalogue de la Collection d'Anatomie de Ger. & W. Vrolik, par J. L. Dusseau. 8vo. *Amsterdam* 1865.	———
Hippocratis et Aliorum Medicorum Veterum Reliquiæ, edidit F. Z. Ermerins. Vol. III. 4to. *Traj. ad Rhen.* 1864.	———
Antwerp:—Congrès Archéologique International, Aout 1866. 4to. *Anvers* 1866.	The Congress.
Apt:—Annales de la Société Littéraire, Scientifique et Artistique d'Apt [Vaucluse]. Première Année 1863–64, Deuxième Année, fasc. 1. 8vo. *Apt* 1865–66.	The Society.
Basel:—Verhandlungen der Naturforschenden Gesellschaft. Theil IV. Heft 2. 8vo. *Basel* 1866.	The Society.
Batavia:—	
Verhandelingen van het Bataviaasch Genootschap van Kunsten en Wetenschappen. Deel XXX. & XXXI. 4to. *Batavia* 1863–64.	The Society.

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
Batavia :—Tijdschrift voor Indische Taal-, Land- en Volkenkunde. Deel XIII. Afl. 1–6; Deel XIV. Afl. 1–4. 8vo. *Batavia* 1863–64.	The Society.
Notulen van de Algemeene en Bestuurs-Vergaderingen. Deel. I. Afl. 1–4. 8vo. *Batavia* 1863–64.	———
Natuurkundig Tijdschrift voor Nederlandsch Indië, uitgegeven door de Koninklijke Natuurkundige Vereeniging in Nederlandsch Indië. Deel XXVI. Afl. 3–6; Deel XXVII. & XXVIII. 8vo. *Batavia* 1864–65.	The Union.
Berlin :—Abhandlungen der Königlichen Akademie der Wissenschaften, aus dem Jahre 1864. 4to. *Berlin* 1865.	The Academy.
Monatsberichte. Aus dem Jahre 1865, Januar 1866. 8vo. *Berlin* 1866.	———
Die Fortschritte der Physik im Jahre 1863, dargestellt von der Physikalischen Gesellschaft. Jahrgang XIX. 8vo. *Berlin* 1865.	The Society.
Bern :—Mittheilungen der Naturforschenden Gesellschaft aus dem Jahre 1864, Nr. 553–579; 1865, Nr. 580–602. 8vo. *Bern* 1864–66.	The Society.
Birmingham :—Institution of Mechanical Engineers. Proceedings, 1864, 2nd and 3rd August, Part 3; 3rd November; 1865, 26th January, 4th May, 1st and 2nd August, Parts 1–3. 8vo. *Birmingham* 1864–65.	The Institution.
Bologna :—	
Memorie della Accademia delle Scienze dell' Istituto. Serie seconda. Tomo 3, fasc. 1–4; tomo 4, fasc. 1. Indici Generali. 4to. *Bologna* 1863–65.	The Academy.
Rendiconto delle Sessioni 1863–64. 8vo. *Bologna* 1864.	———
Boston :—	
American Academy of Arts and Sciences. Proceedings. Vol. VI. Sheets 23–38. 8vo. *Boston* 1864–65.	The Academy.
Society of Natural History. Proceedings. Vol. VI. Sheets 23–27, and Index. Vols. VII., VIII., & IX. Sheets 1–3, 21–24, and Index. 8vo. *Boston* 1858–65.	The Society.
Breslau :—Abhandlungen der Schlesischen Gesellschaft für vaterländische Cultur. Abtheilung für Naturwissenschaften und Medicin. 1864. Philosophisch-historische Abtheilung. 1864, Heft 2. Zweiundvierzigster Jahresbericht. 8vo. *Breslau* 1864–65.	The Society.
Brünn :—Verhandlungen des Naturforschenden Vereines. Band III. 1864. 8vo. *Brünn* 1865.	The Union.
Brussels :—	
Mémoires Couronnés et Mémoires des Savants Étrangers de l'Académie Royale des Sciences, des Lettres et des Beaux Arts. Tome XXXII. 4to. *Bruxelles* 1865.	The Academy.
——— Bulletins. 2^e série. Tomes XVIII., XIX., XX., & XXI. Nos. 1 & 2, 4 & 5. 8vo. *Bruxelles* 1865–66.	———
——— Mémoires Couronnés et autres Mémoires. Tome XVII. 8vo. *Bruxelles* 1865.	———
———. Annuaire 1865. 8vo. *Bruxelles*.	———
Bulletin de l'Académie Royale de Médecine. 2^e série. Tome VII. No. 7; Tome VIII. Nos. 3–11. 8vo. *Bruxelles* 1864–66.	———
Calcutta :—	
Asiatic Society of Bengal. Journal. Index and Contents of Vol. XXXIII. New Series, 1865, Part. 1, Nos. 1–3; Part 2, Nos. 1–3. 8vo. *Calcutta* 1865.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Calcutta :—	
Geological Survey of India. Memoirs. Vol. IV. Part 3, Vol. V. Part 1. 8vo. *Calcutta* 1865.	The Museum of Geology.
——— Palæontologia Indica: III. (6–9), IV. (1). 4to. *Calcutta* 1865.	———
Annual Report, 1864–65. Catalogue of the Specimens of Meteoric Stones. Catalogue of the Organic Remains belonging to the Echinodermata. 8vo. *Calcutta* 1865.	———
Cambridge (Mass.):—	
Museum of Comparative Zoology. Bulletin. 8vo. 1865.	Prof. L. Agassiz, For. Mem. R.S.
——— Annual Report of the Trustees, 1864. 8vo. *Boston* 1865.	———
——— Illustrated Catalogue of the Museum. No. 1, Ophiuridæ and Astrophytidæ, by T. Lyman. No. 2, North American Acalephæ, by A. Agassiz. 8vo. *Cambridge* 1865.	———
National Academy of Sciences. Annual for 1863–64. 8vo. *Cambridge* 1865.	The Academy.
——— Letter of the President, 1865.	———
Christiania :—	
Index Scholarum in Universitate Regia Fredericiana, 1865. 4to. *Christiania.*	The University.
Aarsberetning for Aaret 1863. 8vo. *Christiania* 1865.	———
Gaver til Universitets Bibliothek. 8vo. *Christiania* 1862–65.	———
Veiviser ved Geologiske Excursioner i Christiania Omegn, af Lector Theodor Kjerulf. 4to. *Christiania* 1865.	———
Om de i Norge Forekommende Fossile Dyrelevninger fra Quartærperioden, af M. Sars. 4to. *Christiania* 1865.	———
Norges Ferskvandskrebsdyr af G. O. Sars. 4to. *Christiania* 1865.	———
Nyt Magazin for Naturvidenskaberne. Bind XIII. Heft 4; Bind XIV. Heft. 1. 8vo. *Christiania* 1864–65.	———
Meteorologische Beobachtungen; aufgezeichnet auf Christiania Observatorium. I. Band, letzte Lieferung. 4to. *Christiania* 1865.	———
Meteorologiske Iagttagelser, 1864. 4to. *Christiania* 1865.	———
Columbus :—Eighteenth Annual Report of the Ohio State Board of Agriculture for 1863. 8vo. *Columbus* 1864.	The Board.
Copenhagen :—	
Oversigt over det Kgl. danske Videnskabernes Selskabs Forhandlinger i Aaret 1864. 8vo. *Kjöbenhavn.*	The Society.
Regiæ Universitatis Havniensis Anniversaria. 4to. *Havniæ* 1824.	J. J. S. Steenstrup, For. Mem. R.S.
Videnskabelige Meddelelser fra den naturhistoriske Forening. 1849–64. 17 Parts. 8vo. *Kjöbenhavn* 1849–64.	The Union.
Danzig :—Schriften der Naturforschenden Gesellschaft, neue Folge. Band I. Heft 1 & 2. 8vo. *Danzig* 1863–65.	The Society.
Dresden :—Erster und zweiter Jahresberichte des Vereins für Erdkunde. 8vo. *Dresden* 1865.	The Union.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Dublin:—	
Royal Dublin Society. Journal. No. 34. 8vo. *Dublin* 1865.	The Society.
Royal Geological Society of Ireland. Journal. Vol. I. Part 1. 8vo. 1864–65. 8vo. 1865.	The Society.
Royal Irish Academy. Transactions. Vol. XXIV. Science, Parts 4 & 6; Antiquities, Parts 2, 3 & 4; Polite Literature, Part 2. 4to. *Dublin* 1864–65.	The Academy.
Proceedings. Vol. VIII.; Vol. IX. Part 1. 8vo. *Dublin* 1865.	———
Edinburgh:—	
Royal Society. Transactions. Vol. XXIV. Part 1. 4to. *Edinburgh* 1865.	The Society.
——— Proceedings. 1864–65. Vol. V. No. 65. 8vo. *Edinburgh* 1865.	———
Royal Scottish Society of Arts. Transactions. Vol. VII. Part 1. 8vo. *Edinburgh* 1865.	———
Falmouth:—Royal Cornwall Polytechnic Society. Thirty-second Annual Report. 1864. 8vo. *Falmouth.*	The Society.
Florence:—Annali del R. Museo di Fisica e Storia Naturale di Firenze per il 1865. Nuova Serie. Vol. I. 4to. *Firenze* 1866.	The Museum.
Frankfort:—	
Abhandlungen herausgegeben von der Senckenbergischen naturforschenden Gesellschaft. Band V. Heft 3 & 4. 4to. *Frankfurt a. M.* 1865.	The Society.
Zoologische Gesellschaft. Der Zoologische Garten. Jahrgang VI. No. 1–12. 8vo. *Frankfurt a. M.* 1865.	———
Freiburg im Breisgau:—Berichte über die Verhandlungen der Naturforschenden Gesellschaft. Band III. Heft 3 & 4. 8vo. *Freiburg i. Br.* 1865.	The Society.
Geneva:—	
Mémoires de l'Institut National Génevois. Tome I. (Année 1853) to Tome X. (Années 1864–1865). 10 Vols. 4to. *Genève* 1854–66.	The Institute.
Bulletin de l'Inst. Nat. Génevois. Tomes I.–XIII., and Nos. 27 & 28. 8vo. *Genève* 1853–66.	———
Mémoires de la Société de Physique et d'Histoire Naturelle. Tome XVIII. Première Partie. 4to. *Genève* 1865.	The Society.
Göteborg:—K. Vetenskaps och Vitterhets Samhälles Handlingar. Ny Tidsföljd. IX. Häftet. 8vo. *Göteborg* 1864.	The Society.
Göttingen:—Nachrichten von der K. Gesellschaft der Wissenschaften und der Georg-August Universität aus dem Jahre 1865. 8vo. *Göttingen* 1865.	The Society.
Haarlem:—Natuurkundige Verhandelingen van de Hollandsche Maatschappij der Wetenschappen, Tweede Verzameling. Deel XXI., Stuk 2; Deel XXII., Stuk 1 & 2; Deel XXIII. 4to. *Haarlem* 1864–65.	The Society.
Halle:—Naturwissenschaftliche Vereine für Sachsen und Thüringen. Zeitschrift für die gesammten Naturwissenschaften: redigirt von C. Giebel und M. Siewert. Jahrg. 1864, Band XXIV.; Jahrg. 1865, Band XXV. & XXVI. 8vo. *Berlin* 1864–65.	The Unions.
Havana:—Observatorio Magnético y Meteorológico del Real Colegio de Belen. Resumen de las Observaciones. Abril–Agosto 1865. 8vo. *Habana.*	The Observatory.
Hobart Town:—	
Royal Society of Tasmania. Monthly Notices of Papers and Proceedings 1863 & 1864.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Hobart Town:—Royal Society of Tasmania. Reports, 1861, 1863, 1864. 8vo. *Hobart Town* 1862–65.	The Society.
Jena:—Jenaische Zeitschrift für Medicin und Naturwissenschaft, herausgegeben von der Medicinisch-Naturwissenschaftlichen Gesellschaft zu Jena. Band I. Heft 4; Band II. Heft 1–4. 8vo. *Leipzig* 1864–66.	The Society.
Kiel:—Schriften der Universität, aus dem Jahre 1864. Band XI. 4to. *Kiel* 1865.	The University.
Kolozsvárt:—Az Erdélyi Muzeum. Egylet Évkönyvei. Kötet III. Füzet 2. 4to. *Kolozsvárt* 1866.	The Museum.
Königsberg:—Schriften der Königlichen Physikalisch-Oekonomischen Gesellschaft. Jahrgang V. 1864. Abtheilung 1 & 2. 4to. *Königsberg* 1864.	The Society.
Lausanne:—Bulletin de la Société Vaudoise des Sciences Naturelles. Tome VIII. No. 53. 8vo. *Lausanne* 1865.	The Society.
Leeds:—	
Geological and Polytechnic Society of the West Riding of Yorkshire. Report of the Proceedings, 1864–65. 8vo. *Leeds* 1866.	The Society.
Philosophical and Literary Society. Forty-fifth Report of the Council. 8vo. *Leeds* 1865.	The Society.
——————— Catalogue of the Library. 8vo. *Leeds* 1866.	———
Leipzig:—	
Abhandlungen der Mathematisch-Physischen Classe der Königlich-Sächsischen Gesellschaft der Wissenschaften. Band VII. Nos. 1–4; Band VIII. No. 1. Phil.-Hist. Classe, Band IV. Nos. 5, 6; Band V. No. 1. 8vo. *Leipzig* 1864–65.	The Society.
Berichte über die Verhandlungen. Math.-Phys. Classe, 1864. Phil.-Hist. Classe 1864. 1, 2. 8vo. *Leipzig* 1864–65.	———
Lisbon:—Annaes do Observatorio do Infante D. Luiz. Vol. II. Nos. 4–12; Vol. III. Nos. 1–3. fol. *Lisbôa* 1864–65.	The Observatory.
Liverpool:—	
Historic Society of Lancashire and Cheshire. Transactions. New Series. Vol. IV. 8vo. *Liverpool* 1864.	The Society.
Literary and Philosophical Society. Proceedings. No. 19. 1864–65. 8vo. *London* 1866.	The Society.
London:—	
Anthropological Society. The Anthropological Review. Nos. 9–13. 8vo. *London* 1865–66.	The Society.
——————— The Negro in Jamaica, by Commander Bedford Pim. 8vo. *London* 1866.	———
Art Union. Twenty-ninth Annual Report. 8vo. *London* 1865.	The Art Union.
Board of Trade. Meteorological Papers, Twelfth, Thirteenth, and Fourteenth Numbers. 8vo. & 4to. *London* 1865.	The Board.
British Association. Report of the Thirty-fourth Meeting, held at Bath in September 1864. 8vo. *London* 1865.	The Association.
British Horological Institute. The Horological Journal. Nos. 83–86, 88, 89, 91–94. 8vo. *London* 1865–66.	The Institute.
British Meteorological Society. Proceedings. Vol. II. No. 20; Vol. III. Nos. 21–25. 8vo. *London* 1865–66.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
London:—	
British Museum:—	
List of the Specimens of Lepidopterous Insects in the Collection of the British Museum. 34 Parts. 12mo. *London* 1854–65.	The Trustees of the British Museum.
Catalogue of Lepidopterous Insects. Part 1. Papilionidæ. 4to. *London* 1852.	———
Specimen of a Catalogue of Lycænidæ, by W. C. Hewitson. 4to. *London* 1862.	———
Catalogue of the Specimens of Neuropterous Insects. 4 Parts. 12mo. *London* 1852–53.	———
List of the Specimens of Homopterous Insects. 4 Parts and Supplement. 12mo. *London* 1850–58.	———
List of the Specimens of Dipterous Insects. 7 Parts. 12mo. *London* 1848–55.	———
List of the Specimens of Hymenopterous Insects. Part 2. 12mo. *London* 1848.	———
Catalogue of Hymenopterous Insects. 7 Parts. 12mo. *London* 1853–59.	———
Catalogue of British Hymenoptera. Part 1. 12mo. *London* 1855.	———
Catalogue of British Fossorial Hymenoptera, Formicidæ, and Vespidæ. 12mo. *London* 1858.	———
List of the Specimens of Hemipterous Insects. 2 Parts. 12mo. *London* 1851–52.	———
List of the Coleopterous Insects. Part 1. 12mo. *London* 1851.	———
Nomenclature of Coleopterous Insects. Parts 4 & 6. 12mo. *London* 1849–52.	———
Catalogue of Coleopterous Insects. Parts 7, 8 & 9. 12mo. *London* 1853–56.	———
List of British Curculionidæ, with Synonyma. 12mo. *London* 1856.	———
Catalogue of British Ichneumonidæ. 12mo. *London* 1856.	———
Catalogue of the Coleopterous Insects of Madeira, by T. V. Wollaston. 8vo. *London* 1857.	———
Catalogue of Hispidæ, by Joseph S. Baly. Part 1. 8vo. *London* 1858.	———
Catalogue of Halticidæ, by the Rev. Hamlet Clark. Part 1. 8vo. *London* 1860.	———
Catalogue of the Coleopterous Insects of the Canaries, by T. V. Wollaston. 8vo. *London* 1864.	———
Catalogue of the Specimens of Neuropterous Insects, by Dr. H. Hagen. Part 1. 12mo. *London* 1858.	———
Catalogue of Orthopterous Insects. Part 1. Phasmidæ, by J. O. Westwood. 4to. *London* 1859.	———
List of the Specimens of Myriapoda. 12mo. *London* 1844.	———
Catalogue of the Myriapoda. Part 1. 12mo. *London* 1856.	———
List of the Specimens of Mammalia. 12mo. *London* 1848.	———
Catalogue of the Bones of Mammalia. 8vo. *London* 1862.	———
Catalogue of the Specimens of Mammalia. 3 Parts. 12mo. *London* 1850–52.	———
List of the Specimens of British Animals. Parts 1, 4, 5, 7, 9, 11, 12, 13–17, and Fish. 12mo. *London* 1848–55.	———

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
London :—	
British Museum :—	
List of the Specimens of British Sponges. 12mo. *London* 1848.	The Trustees of the British Museum.
List of British Diatomaceæ. 12mo. *London* 1859.	———
Catalogue of the Conchifera or Bivalve Shells. 2 Parts. 12mo. *London* 1853–54.	———
List of the Shells of Cuba. 12mo. *London* 1854.	———
List of the Shells of South America. 12mo. *London* 1854.	———
List of the Shells of the Canaries. 12mo. *London* 1854.	———
Catalogue of the Collection of Mazatlan Shells. 12mo. *London* 1857.	———
List of the Specimens of Crustacea. 12mo. *London* 1847.	———
Catalogue of Crustacea. Part 1. 12mo. *London* 1855.	———
Catalogue of the Specimens of Amphipodous Crustacea, by C. Spence Bate. 8vo. *London* 1862.	———
Catalogue of the Mollusca. Parts 2 & 4. 12mo. *London* 1850–53.	———
List of the Mollusca. 2 Parts. 12mo. *London* 1855–65.	———
Nomenclature of Molluscous Animals and Shells. Part 1. 12mo. *London* 1850.	———
List of Mollusca and Shells. 12mo. *London* 1855.	———
Catalogue of Phaneropneumona. 12mo. *London* 1852.	———
Catalogue of Auriculidæ, Proserpinidæ, and Truncatellidæ. 12mo. *London* 1857.	———
Catalogue of the Bivalve Mollusca. Part 1. 12mo. *London* 1850.	———
Catalogue of Pulmonata or Air-breathing Mollusca. Part 1. 12mo. *London* 1855.	———
Guide to the Systematic Distribution of Mollusca, by J. E. Gray. 8vo. *London* 1857.	———
Catalogue of the Genera and Subgenera of Birds. 12mo. *London* 1855.	———
List of the Specimens of Birds. Parts 1, 2, 3. Sections 2 & 4. 12mo. *London*. 1844–56.	———
Catalogue of British Birds, by G. R. Gray. 8vo. *London* 1863.	———
Catalogue of the Birds of the Tropical Islands of the Pacific Ocean, by G. R. Gray. 8vo. *London* 1859.	———
Catalogue of the Mammalia and Birds of New Guinea, by J. E. Gray and G. R. Gray. 8vo. *London* 1859.	———
Catalogue of the Specimens and Drawings of Mammals, Birds, Reptiles, and Fishes of Nepal and Tibet. 12mo. *London* 1863.	———
List of the Osteological Specimens. 12mo. *London* 1847.	———
Catalogue of the Specimens of Amphibia. Part 2. 12mo. *London* 1850.	———
Catalogue of the recent Echinida or Sea-eggs. Part 2. 12mo. *London* 1855.	———
Catalogue of Fish, by L. T. Gronow. 12mo. *London* 1854.	———
List of the Specimens of Fish. Part 1. 12mo. *London* 1851.	———
Catalogue of Lophobranchiate Fish. 12mo. *London* 1856.	———
Catalogue of Apodal Fish, by Dr. Kaup. 8vo. *London* 1856.	———

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
London:—	
British Museum:—	
Catalogue of the Acanthopterygian Fishes, by Dr. A. Günther. 5 Vols. 8vo. *London* 1859–64.	The Trustees of the British Museum.
Catalogue of the Species of Entozoa or Intestinal Worms. 12mo. *London* 1853.	———
Catalogue of the British Non-Parasitical Worms, by George Johnston. 8vo. *London* 1865.	———
Catalogue of Colubrine Snakes. 12mo. *London* 1858.	———
Catalogue of the Tortoises, Crocodiles, and Amphisbænians. 12mo. *London* 1844.	———
Catalogue of the Specimens of Lizards. 12mo. *London* 1845.	———
Catalogue of Shield Reptiles in the Collection of the British Museum. Part 1. Testudinata (Tortoises), by J. E. Gray. 4to. *London* 1855.	———
Catalogue of the Batrachia Salientia, by Dr. A. Günther. 8vo. *London* 1858.	———
Catalogue of the Collection of Meteorites in the Mineral Department. 8vo. *London* 1866.	———
A Guide to the First Vase Room in the Department of Greek and Roman Antiquities. 8vo. *London* 1866.	———
British Pharmaceutical Conference. Proceedings. Birmingham Meeting, 1865. 8vo. *London* 1865.	The Conference.
Chemical Society. Journal. Series 2. Vol. III. May to December 1865; Vol. IV. January to June 1866. 8vo. *London*.	The Society.
Entomological Society. Transactions. Vol. II. Parts 5 & 6. Vol. III. Part 2; Vol. IV. Part 1; Vol. V. Parts 1 & 2. 8vo. *London* 1865–66.	The Society.
Epidemiological Society. Transactions. Vols. I. & II. Part 1. 8vo. *London* 1863–65.	The Society.
——— Report on the Questions submitted by Dr. Farr to the Council, concerning the Classification of Epidemic Diseases. 8vo. *London* 1865.	———
Geological Society. Quarterly Journal. Vol. XXI. Parts 3 & 4; Vol. XXII. Parts 1 & 2. 8vo. *London* 1865–66. List, December 31, 1865.	The Society.
Geological Survey of Great Britain. Memoirs. Vol. III. 8vo. *London* 1866.	The Museum of Practical Geology.
Institution of Civil Engineers. Address of John Fowler on his Election as President. List of Members. 8vo. *London* 1866.	The Institution.
Linnean Society. Transactions. Vol. XXV. Part 1. 4to. *London* 1865.	The Society.
——— Journal. Zoology: Vol. VIII. Nos. 31 & 32; Vol. IX. No. 33. Botany: Vol. IX. Nos. 35–37. 8vo. *London* 1865–66.	———
Pathological Society. Transactions. Vol. XVI. 8vo. *London* 1865.	The Society.
Photographic Society. The Photographic Journal. Nos. 159–169. 8vo. *London* 1865–66.	The Society.
Royal Agricultural Society. Journal. Second Series. Vol. I. Part 2; Vol. II. Part 1. 8vo. *London* 1865.	The Society.
Royal Asiatic Society. Journal. New Series. Vol. I. Part 2; Vol. II. Part 1. 8vo. *London* 1865–66.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
London:—	
Royal Astronomical Society. Memoirs. Vol. XXXIII. 4to. *London* 1865.	The Society.
———— Monthly Notices. Vol. XXV. Nos. 8 & 9; Vol. XXVI. Nos. 1–7. 8vo. *London* 1865–66.	————
Royal College of Surgeons. Calendar. July 13, 1865. 8vo. *London* 1865.	The College.
———— Catalogue of the Specimens of Entozoa in the Museum, by T. S. Cobbold. 8vo. *London* 1866.	————
Royal Geographical Society. Journal. Vol. XXXV. 8vo. *London* 1865.	The Society.
———— Proceedings. Vol. X. Nos. 1–3. 8vo. *London* 1865–66.	————
———— Catalogue of the Library. 8vo. *London* 1865.	————
Royal Horticultural Society. Proceedings. Vol. V. Nos. 7, 8, 9; New Series, Vol. I. Nos. 1–4. 8vo. *London* 1865–66.	The Society.
———— Journal. Edited by the Rev. M. J. Berkeley. New Series. Vol. I. Parts 1 & 2. 8vo. *London* 1866.	————
Royal Institute of British Architects. Sessional Papers, 1865–66. Part 1. Nos. 1–4; Part 2. Nos. 1–5, 1864–65; Part 3. Nos. 1, 2, 5. 4to. *London*.	The Institute.
———— Catalogue of the Printed Books and Manuscripts in the Library. 4to. *London* 1865.	————
Royal Institution. Proceedings. Vol. IV. Parts 5–7. 8vo. *London* 1865–66.	The Institution.
Royal Medical and Chirurgical Society. Medico-Chirurgical Transactions. Vol. XLVIII. 8vo. *London* 1865.	The Society.
———— Proceedings. Vol. V. Nos. 2–4. 8vo. *London* 1865–66.	————
Royal Society of Literature. Transactions. Second Series. Vol. VIII. Part 2. 8vo. *London* 1865.	The Society.
Royal United Service Institution. Journal. Vol. IX. Nos. 34–37, and Appendix. 8vo. *London* 1865–66.	The Institution.
Saint Bartholomew's Hospital Reports. Edited by Dr. Edwards and G. W. Callender. Vol. I. 8vo. *London* 1865.	The Hospital.
Society of Antiquaries. Archæologia. Vol. XXXIX. Part 2. 4to. *London* 1865.	The Society.
———— Proceedings. Second Series. Vol. II. No. 6. 8vo. *London* 1864.	————
Society of Arts. Journal. July to December 1865; January to June 1866. 8vo. *London* 1865–66.	The Society.
University College Calendar, Session 1865–66. 8vo. *London* 1865.	The College.
Zoological Society. Transactions. Vol. V. Part 4. 4to. *London* 1865.	The Society.
———— Proceedings of the Scientific Meetings for 1864. 3 Parts. 8vo. *London*.	————
Luxembourg:—Société des Sciences Naturelles du Grand Duché de Luxembourg. Tome VIII. Année 1865. 8vo. *Luxembourg* 1865.	The Society.
Lyons:—Société des Sciences Médicales. Vaccine et Variole, Nouvelle étude expérimentale sur la question de l'identité de ces deux Affections, Rapport par A. Chauveau, Viennois, et P. Meynet. 8vo. *Paris* 1865.	The Society.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Madrid:—	
Memorias de la Real Academia de Ciencias Exactas, Fisicas y Naturales. Tomo VI. 2ª serie: Ciencias Fisicas. Tomo II. Parte 1 & 2. 4to. *Madrid* 1864–65.	The Academy.
——— Resumen de las Actas en el año Academico de 1862 á 1863. 4to. *Madrid* 1864.	———
Anuario del Real Observatorio, Sexto Año 1865. 8vo. *Madrid* 1864.	The Observatory.
Melbourne:—The Melbourne University Calendar for 1865–66. 8vo. *Melbourne.*	The University.
Mende:—Bulletin de la Société d'Agriculture, Industrie, Science et Arts du Département de la Lozère. Nos. 28 & 29. 8vo. *Mende* 1852.	The Society.
Milan:—	
Memorie del Reale Istituto Lombardo di Scienze e Lettere. Classe di Scienze Matematiche e Naturali. Vol. X. fasc. 1. Classe di Lettere e Scienze Morali e Politiche. Vol. X. fasc. 1. 4to. *Milano* 1865.	The Institute.
——— Rendiconti. Classe di Scienze Matematiche e Naturali: Vol. I. fasc. 9 & 10; Vol. II. fasc. 1 & 2. Classe di Lettere: Vol. I. fasc. 8–10; Vol. II. fasc. 1 & 2. 8vo. *Milano* 1864–65.	———
Atti della Società Italiana di Scienze Naturali. Vol. VI. fasc. 4 & 5; Vol. VII. & Vol. VIII. fasc. 1 & 2. 8vo. *Milano* 1864–65.	The Society.
Montreal:—	
The McGill University Calendar and Examination Papers, 1865–66. 8vo. *Montreal* 1865.	The University.
The Canadian Naturalist and Geologist. New Series. Vol. II. Nos. 1–4. 8vo. *Montreal* 1865.	The Natural History Society.
Numismatic and Antiquarian Society. Constitution and By-Laws. 12mo. *Montreal* 1866.	S. C. Bagg, Esq.
——— The Antiquities and Legends of Durham. By S. C. Bagg. 8vo. *Montreal* 1866.	———
Moscow:—Bulletin de la Société Impériale des Naturalistes. Année 1864. Nos. 2–4; Année 1865. Nos. 1 & 2. 8vo. *Moscou* 1864–65.	The Society.
Munich:—	
Abhandlungen der Königlich-Bayerischen Akademie der Wissenschaften. Philos.-Philol. Classe: Band X. Abth. 2. Hist. Classe: Band IX. Abth. 1 & 2. 4to. *München* 1865.	The Academy.
Sitzungsberichte: 1865, I., Hefte 1–4; II., Hefte 1–4; 1866, I., Hefte 1 & 2. 8vo. *München* 1865–66.	———
Die Verhandlungen der protestantischen Fürsten in den Jahren 1590 und 1591 zu Gründung einer Union. Vortrag von K. A. Muffat. 4to. *München* 1865.	———
Induction und Deduction, von Justus von Liebig. 8vo. *München* 1865.	———
Entstehung und Begriff der Naturhistorischen Art, von Dr. C. Nägeli. Zweite Auflage. 8vo. *München* 1865.	———
Naples:—	
Società Reale. Rendiconto delle tornate e dei lavori dell' Accademia di Scienze Morali e Politiche. Anno IV. Feb.–Maggio 1865. 8vo. *Napoli* 1865.	The Society.
——— Rendiconto della Reale Accademia di Archeologia, Lettere e Belle Arti. Anno 1864, Luglio–Dicembre. 4to. *Napoli* 1864.	———

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Neuchâtel:—Bulletin de la Société des Sciences Naturelles. Tome VII. premier cahier. 8vo. *Neuchatel* 1865.	The Society.
Newcastle-upon-Tyne:—Natural History Transactions of Northumberland and Durham. Vol. I. Part 1. 8vo. *Newcastle* 1865.	The Tyneside Naturalists' Field Club.
New York:—	
Lyceum of Natural History. Annals. Vol. VIII. Nos. 2 & 3. 8vo. *New York* 1864.	The Lyceum.
———— Charter, Constitution, and By-Laws, 1864.	————
American Geographical and Statistical Society. Proceedings. Vol. II. Nos. 3 & 4. 8vo. *New York* 1863–65.	The Society.
Oxford:—Ashmolean Society. Transactions. Vol. II. Nos. 8, 9, 12, 13, 14, 15; Vol. III. Nos. 1, 2, 3. Proceedings. Vol. III. Nos. 33, 34, 35. 8vo. *Oxford* 1841–57.	The Society.
Palermo:—Giornale di Scienze Naturali ed Economiche pubblicato per cura del Consiglio di Perfezionamento annesso al R. Istituto Tecnico di Palermo. Vol. I. fasc. 1 & 2. Imp. 8vo. *Palermo* 1865.	The Institute.
Paris:—	
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences. June to December 1865, January to June 1866. Tomes LX. & LXI. Tables des Matières. 4to. *Paris.*	The Institute.
Dépôt de la Marine: Annales Hydrographiques, 1er–4^{e} Trimestre de 1864; 1er Trimestre de 1865. 8vo. *Paris.*	The Dépôt de la Marine.
———— Recherches sur les Chronomètres. VII^{e} Cahier. 8vo. *Paris* 1864.	————
———— Annuaire des Marées des Côtes de France pour l'an 1866. 12mo. *Paris* 1865.	————
———— La Loi des Tempêtes, par H. W. Dove, traduit par A. Le Gras. 8vo. *Paris* 1864.	————
———— Madagascar (Côte Orientale), par M. Germain. 8vo. *Paris* 1864.	————
———— Mer du Nord. IV^{e} partie, traduit par A. Le Gras. 8vo. *Paris* 1864.	————
———— Instructions Nautiques pour les principaux ports de la côte Est d'Amérique du Nord, traduit par M. MacDermott. 8vo. *Paris* 1864.	————
———— Manuel de la Navigation dans la Mer des Antilles et dans le Golfe du Mexique, par C. P. de Kerhallet. 3^{e} partie. 8vo. *Paris* 1864.	————
———— Routier de la Côte Nord d'Espagne, traduit par A. Le Gras. 8vo. *Paris* 1864.	————
———— Instructions Nautiques sur les Côtes de Corse, par Sallot des Noyers. 8vo. *Paris* 1865.	————
———— Instruction pour le Micromètre Lugeol à Cadran Lorieux, par M. Box. 8vo. *Paris* 1865.	————
———— Renseignements sur la Navigation des Côtes et des Rivières de la Guyane Française, par E. Couy. 8vo. *Paris* 1865.	————
Annales des Mines. Sixième série. Tome VII., 2^{e} & 3^{e} liv. de 1865; Tome VIII., 4–6^{e} liv. de 1865; Tome IX. 1^{r} liv. de 1866. 8vo. *Paris* 1865–66.	L'École des Mines.

Presents.	Donors.
ACADEMIES and SOCIETIES (*continued*).	
Paris:—	
Journal de l'École Impériale Polytechnique. Cahier 41. Tome XXIV. 4to. *Paris* 1865.	L'École Polytechnique.
Annales Scientifiques de l'École Normale Supérieure. Tome III. Nos. 1 & 2. 4to. *Paris* 1866.	L'École Normale.
Bulletin de la Société d'Encouragement pour l'Industrie Nationale. 2^e série. Tome XII. May to December 1865; Tome XIII. January to April 1866. 4to. *Paris.*	The Society.
Annales de la Société Entomologique de France. Tome VII. 2–4 Trimestre. 8vo. *Paris* 1838.	The Society.
Bulletin de la Société de Géographie. 5^e série. Tome VIII. & Tome X. Année 1865, Juillet–Déc.; Tome XI. Janv.–Mai 1866. 8vo. *Paris* 1864–66.	The Society.
——— Recueil de Voyages et de Mémoires. Tome VII. partie 1. 4to. *Paris* 1844.	———
Bulletin de la Société Géologique. 2^e série. Tome XXII. feuilles 8–36; Tome XXIII. feuilles 1–12. 8vo. *Paris* 1864–66.	The Society.
Perpignan:—Société Agricole, Scientifique, et Littéraire des Pyrénées-Orientales. Vol. XIII. 8vo. *Perpignan* 1863.	The Society.
Philadelphia:—	
American Philosophical Society. Transactions. Vol. XIII. Parts 1 & 2. 4to. *Philadelphia* 1865.	The Society.
——— Proceedings. Vol. IX. Nos. 71 & 72; Vol. X. No. 74. 8vo. *Philadelphia* 1864–65. List of Members.	———
Franklin Institute. Journal. Vol. LXXXI. Nos. 481–483. 8vo. *Philadelphia* 1866.	The Institute.
Portland (U. S.):—	
Society of Natural History. Proceedings. Vol. I. Part 1. 8vo. *Portland* 1862.	The Society.
——— Journal. Vol. I. No. 1. 8vo. *Portland* 1864.	———
Prague:—	
Abhandlungen der Königlichen Böhmischen Gesellschaft der Wissenschaften. Fünfter Folge Band XIII. 4to. *Prague* 1865.	The Society.
Sitzungsberichte. Jahrgang 1864. 2 Parts. 8vo. *Prag* 1865.	———
Rio de Janeiro:—Archivos da Palestra Scientifica. Vol. I. 4to. *Rio de Janeiro* 1858.	J. Miers, F.R.S.
Roma:—Collegio Romano. Bullettino Meteorologico. Vol. IV. Nos. 5 & 6, 9–12; Vol. V. Nos. 1, 3, 4. 4to. *Roma* 1865–66.	The College.
St. Andrews:—University Calendar for the year 1866–67. 8vo. *Edinburgh* 1866.	The University.
St. Petersburg:—	
Mémoires de l'Académie Impériale des Sciences. VII^e. série. Tomes VII. & VIII. 4to. *St. Pétersbourg* 1863–65.	The Academy.
Bulletin. Tome VII. Nos. 3–6; Tome VIII. Nos. 1–6. 4to. *St. Pétersbourg* 1864–65.	———
МОРСКОЙ СБОРНИКЪ (Marine Collections). Nos. 1–4. 8vo. 1866.	The Compass Observatory, Cronstadt.
Salem:—Essex Institute. Proceedings. Vol. IV. No. 7. 8vo. *Salem* 1866.	The Institute.

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
Shanghai:—	
Journal of the North China Branch of the Royal Asiatic Society. New Series. Nos. 1 & 2. 8vo. *Shanghai* 1865–66.	The Society.
Report of the Council for the year 1864. 8vo. *Shanghai* 1865.	———
Steiermark:—Mittheilungen des Naturwissenschaftlichen Vereines. Hefte 1–3. 8vo. *Graz* 1863–65.	The Union.
Stockholm:—	
Kongliga Svenska Vetenskaps-Akademiens Handlingar. Ny Följd. Bandet V. Häftet 1. 4to. *Stockholm* 1863.	The Academy.
Öfversigt af . . . Förhandlingar. Årgången XXI. 1864. 8vo. *Stockholm* 1865.	———
Meteorologiska Jakttagelser i Sverige, af E. Edlund. Bandet V. 1863. 4to. *Stockholm* 1865.	———
Toronto:—The Canadian Journal of Industry, Science, and Art. New Series. Nos. 57–62. 8vo. *Toronto* 1865–66.	The Canadian Institute.
Toulouse:—Mémoires de l'Académie Impériale des Sciences, Inscriptions et Belles-Lettres. 6^e série. Tome III. 8vo. *Toulouse* 1865.	The Academy.
Trondhjem:—Det Kongelige Norske Videnskabers-Selskabs Skrifter det 19de Aarhundrede. Bind V. Heft 1. 8vo. *Trondhjem* 1865.	The Society.
Turin:—Memorie della Reale Accademia delle Scienze. Serie seconda. Tomo XXI. 4to. *Torino* 1865.	The Academy.
Atti. Vol. I. Disp. 2 (1865), 1866. 8vo. *Torino* 1866.	———
Upsala:—	
Nova Acta Regiæ Societatis Scientiarum Upsaliensis. Seriei tertiæ Vol. V. fasc. 2. 4to. *Upsaliæ* 1865.	The Society.
Upsala Universitets Årskrift 1864. 8vo. *Upsala* 1864.	The University.
Utrecht:—	
Meteorologische Waarnemingen in Nederland en zijne Bezittingen, en Afwijkingen van Temperatur en Barometerstand op vele plaatsen in Europa. 1864. 4to. *Utrecht* 1865.	The Netherlands Meteorological Institute.
Natuurkundige Verhandelingen uitgegeven door het Provinciaal Utrechtsch Genootschap. Nieuwe Reeks, Deel 1. Stuk 14. 4to. *Utrecht* 1864–65.	The Society.
Verslag van het Verhandelde in de Algemeene Vergadering, 1862–65. 8vo. *Utrecht* 1862–65.	———
Aanteekeningen van het Verhandelde in de Sectie Vergaderingen, 1860–64. 8vo. *Utrecht.*	———
Venice:—	
Memorie dell' I. R. Istituto Veneto di Scienze, Lettere ed Arti. Vol. XII. parte 1 & 2. 4to. *Venezia* 1864–65.	The Institute.
Atti. Serie terza. Tomo X. disp. 5–10; Tomo XI. disp. 1–4. 8vo. *Venezia* 1864–66.	———
Esercitazioni Scientifiche e Letterarie dell' Ateneo Veneto. Tomo III., V. & VI. fasc. 2 & 3; Tomo VII. fasc. 1 & 2. 4to. *Venezia* 1839–60.	The Athenæum.
Atti. Serie 2. Vol. I. puntata 2–4; Vol. II. puntata 1–4; Vol. III. puntata 1. 8vo. *Venezia* 1864–66.	———
Vienna:—	
Denkschriften der Kaiserlichen Akademie der Wissenschaften. Math.-Naturw. Classe. Band XXIV. Phil.-Hist. Classe. Band XIV. 4to. *Wien* 1865.	The Academy.

PRESENTS.	DONORS.
ACADEMIES and SOCIETIES (*continued*).	
Vienna:—	
Sitzungsberichte. Math.-Nat. Classe, Abth. 1: Band L. Hefte 2–5; B. LI. Hefte 1–5; Band LII. Hefte 1 & 2. Abth. 2: Band L. Hefte 1–5; Band LI. Hefte 1–5; Band LII. Hefte 1–3; Register zu den Bänden 43 bis 50. Phil.-Hist. Classe: Band XLVII. Hefte 1 & 2; Band XLVIII. Hefte 1 & 2; Band XLIX. Hefte 1–3; Band L. Hefte 1–4; Band LI. Heft 1; Register zu den Bänden 41 bis 50. 8vo. *Wien* 1864–66.	The Academy.
Almanach. Jahrgang XV. 1865. 8vo. *Wien*.	———
Anzeiger. Jahrgang II., 1865, Nr. 15–29; Jahrgang III., 1866, Nr. 1–3, 6–14. 8vo. *Wien*.	———
Mittheilungen der Kaiserlich-Königlichen Geographischen Gesellschaft. Jahrgang VIII. Heft 1. 8vo. *Wien* 1864.	The Society.
Jahrbuch der K.-K. Geologischen Reichsanstalt. 1865. Band XV. Nr. 1–3. 8vo. *Wien* 1864.	The Establishment.
Verhandlungen der K.-K. Zoologisch-Botanischen Gesellschaft in Wien. Jahrgang 1864. Band XIV. 8vo. *Wien* 1864.	The Society.
Washington:—	
National Academy of Sciences. Report for 1863. 8vo. *Washington* 1864.	The Academy.
Smithsonian Institution. Smithsonian Contributions to Knowledge. Vol. XIV. 4to. *Washington* 1865.	The Smithsonian Institution.
Smithsonian Collections. 8vo. *Washington*:—Monographs of the Diptera of North America, by H. Loew. Part 2. Edited by R. Osten Sacken. 1864. Bibliography of North American Conchology previous to the year 1860, by W. G. Binney. Part 2. 1864. Check List of the Invertebrate Fossils of North America—Cretaceous and Jurassic, by F. B. Meek. 1864. Miocene, by F. B. Meek. 1864. Review of American Birds, by S. F. Baird. Part 1. 1864.	———
Annual Report of the Board of Regents for 1863 & 1864. 8vo. *Washington* 1864–65.	———
Würzburg:—	
Physikalisch-medicinische Gesellschaft. Würzburger Naturwissenschaftliche Zeitschrift. Band VI. Heft 1. 8vo. *Würzburg* 1865.	The Society.
Würzburger Medicinische Zeitschrift. Band VI. Hefte 1–6. 8vo. *Würzburg* 1865.	———
Zürich:—	
Nouveaux Mémoires de la Société Helvétique des Sciences Naturelles. Band XXI. 4to. *Zürich* 1865.	The Society.
Verhandlungen der Schweizerischen Naturforschenden Gesellschaft. 1864. 8vo *Zürich*.	———
Actes de la Société Helvétique des Sciences Naturelles réunie à Genève, Août 1865. 49^{e} Session. 8vo. *Genève*.	———
Geschichte der Schweizerischen Naturforschenden Gesellschaft. 4to. *Zürich* 1865.	———
ACLAND (H. W., F.R.S.) The Harveian Oration, 1865. 8vo. *London* 1865.	The Author.
AGASSIZ (Alexander). Embryology of the Starfish. 4to. *Cambridge* 1864.	The Author.

PRESENTS.	DONORS.
AIRY (G. B., F.R.S.) Astronomical, Magnetical, and Meteorological Observations made at the Royal Observatory, Greenwich, in 1863. 4to. *London* 1865.	The Lords of the Admiralty.
———— Essays on the Invasion of Britain by Julius Cæsar; the Invasion of Britain by Plautius, and by Claudius Cæsar; the Early Military Policy of the Romans in Britain; the Battle of Hastings, with Correspondence. 4to. *London* 1865.	The Author.
ALFONSO X. DE CASTILLA. Libros del Saber de Astronomia; Copilados, Anotados y Comentados por Don Manuel Rico y Sinobas. Tomo III. fol. *Madrid* 1864.	The Academy of Sciences, Madrid.
ANONYMOUS:—	
Almanach der Oesterreichischen Kriegs.-Marine für das Jahr 1866. 5^{er} Jahrgang. 8vo. *Triest* 1866.	The Austrian K. K. Marine.
Almanaque Naútico para 1867, calculado . . . en el Observatorio de Marina de S. Fernando. 8vo. *Cadiz* 1865.	The Observatory.
American Ephemeris and Nautical Almanac for 1866 and 1867. Asteroids for the year 1865. Almanac Catalogue of Zodiacal Stars. 8vo. *Washington* 1864–65.	The U. S. Bureau of Navigation.
Army Medical Department. Statistical, Sanitary, and Medical Reports, Vol. 5, for 1863. 8vo. *London* 1865.	The Department.
Berliner Astronomisches Jahrbuch für 1868: herausgegeben von W. Foerster, unter Mitwirkung von Dr. Powalky. 8vo. *Berlin* 1866.	The Observatory.
Catalogue of Printed Books in the Library of the Foreign Office. 8vo. *London* 1864.	The Foreign Office.
Das Fünfzigjährige Doctor-Jubiläum des Geheimraths Karl. Ernst von Baer am 29 August, 1864. 4to. *St. Petersburg* 1865.	The Academy of Sciences, St. Petersburg.
Dublin International Exhibition, 1865. Kingdom of Italy. Official Catalogue. 8vo. *Turin* 1865.	The Italian Commission.
Entomologist's Annual for 1866. 12mo. *London* 1866.	H. T. Stainton, Esq.
Estadistica Mineral correspondiente al año de 1863, publicada por la direccion General de Agricultura, Industria y Comercio. 4to. *Madrid* 1865.	Don José Emilio de Santos.
First, Second, and Third Reports of the Commissioners appointed to inquire into the Origin and Nature &c. of the Cattle Plague. fol. *London* 1865–66.	Dr. Bence Jones, F.R.S.
List of Members of the Athenæum. 12mo. *London* 1866.	The Club.
London University Calendar for the year 1866. 8vo. *London* 1866.	The University.
Memoria sobre el Movimiento de la Poblacion de España de los años 1858, 1859, 1860 y 1861. 4to. *Madrid* 1863.	Don José Emilio de Santos.
Nachrichten über Leben und Schriften des Herrn Geheimrathes Dr. Karl Ernst von Baer, mitgetheilt von ihm selbst. Veröffentlicht von der Ritterschaft Esthlands. 8vo. *St. Petersburg* 1865.	The Esthlandische Ritterschaft.
Nautical Almanac and Astronomical Ephemeris for 1868 & 1869. 2 vols. 8vo. *London* 1864–65.	The Lords of the Admiralty.
——— Supplements (Ephemerides of the Minor Planets for 1865 & 1866). 8vo. *London.*	———
Nomenclátor que comprende las Poblaciones, Grupos, Edificios, Viviendas, Albergues etc. de las cuarenta y nueve Provincias de España, tomo 1 & 2. fol. *Madrid* 1863–64.	Don José Emilio de Santos.
Observations Météorologiques faites à Nijné-Taguilsk, année 1864. 8vo. *Paris* 1865.	The Prince Demidoff.

Presents.	Donors.
ANONYMOUS (*continued*).	
Prospectus of the Central Hall of Arts and Sciences. fol. *London* 1865.	General Sabine, P.R.S.
Reise der Oesterreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859. Statistisch-Commercieller Theil, von Dr. K. von Scherzer. Band II. 4to. *Wien* 1865.	Dr. K. von Scherzer.
———— Geologischer Theil. Band I. Abtheilung 2. Paläontologie von Neu-Seeland, redigirt von Dr. F. von Hochstetter, Dr. M. Hörnes und F. Ritter von Hauer. 4to. *Wien* 1865.	Dr. F. von Hochstetter.
———— Nautisch-Physicalische Theil, 3. Abtheilung (letzte). 4to. *Wien* 1865.	The Austrian I. R. Navy Board.
———— Map of the Indian Ocean, 1858.	————
Report of a Committee appointed to consider certain questions relating to the Meteorological Department of the Board of Trade. fol. *London* 1866.	The Committee.
Report of Experiments undertaken by Order of the Board of Trade to determine the relative values of Unmalted and Malted Barley as food for Stock. fol. *London* 1866.	J. B. Lawes, F.R.S.
Report of the Astronomer to the Marine Committee Mersey Docks and Harbour Board, December 1865. 8vo. *Liverpool* 1866.	The Committee.
Report of the Commissioner of Patents for the year 1862, Arts and Manufactures. 2 vols. 8vo. *Washington* 1864.	The Patent-Office, Washington.
Report of the Professor of Astronomy in the University of Glasgow. 8vo. *Glasgow* 1866.	The Senate.
Report of the Superintendent of the Coast Survey, showing the progress of the Survey during the year 1862. 4to. *Washington* 1864.	The Survey.
Results of Meteorological Observations made under the direction of the United States Patent Office and the Smithsonian Institution, from 1854 to 1859 inclusive, being a Report of the Commissioner of Patents. Vol. II. Part 1. 4to. *Washington* 1864.	The Smithsonian Institution.
Royal Commission on the Sanitary State of the Army in India. Vol. I. Report of the Commissioners, Minutes, &c. Vol. II. Appendix. 2 vols. fol. *London* 1863.	Dr. T. Graham Balfour, F.R.S.
Statistics of the United Kingdom of Great Britain and Ireland. Reprinted, with additions, from Thom's Irish Almanac. 8vo. *Dublin* 1866.	The Publishers.
Sveriges Geologiska Undersökning af A. Erdmann. 14–18. 8vo. *Stockholm* 1865. Maps.	The Geological Board of Sweden.
Vancouver Island—Exploration, 1864. 8vo. *Victoria* 1865.	Robert Brown, Esq.
Weekly Returns of Births and Deaths in the City of Dublin: Vol. II. Nos. 24–52; Vol. III. Nos. 1–11, 13–24. Quarterly Returns, Nos. 3–9. 8vo. *Dublin* 1864–66.	The Registrar-General for Ireland.
BAIRD (S. F.) The Distribution and Migrations of North-American Birds. 8vo. *New Haven* 1866.	The Author.
BARCLAY (J. G.) Astronomical Observations taken during the years 1862–64 at the private Observatory, Leyton, Essex. 4to. *London* 1865.	The Author.
BATEMAN (J. F., F.R.S.) On the Supply of Water to London from the Sources of the Severn. 8vo. *London* 1865.	The Author.
BELAVENETZ (Captain J.) Deviations of the Compass, and Diagrams, with an article on the Magnetic Character of an Iron-built Armour-plated Battery "Pervenetz," with a Biographical Sketch of Archibald Smith. 8vo. *St. Petersburg* 1865.	The Author.

Presents.	Donors.
BELAVENETZ (Captain J.) Blank Forms for the Computation of the Deviations and Magnetic Observations on Board the Ship. 4to. *St. Petersburg* 1865.	The Author.
BIANCONI (J. J.) Specimina Zoologica Mosambicana. Fasciculus XVI. fol. *Bononiæ* 1862.	The Author.
BLASQUEZ (Pedro y Ignacio) Memoria sobre el Maguey Mexicano (Agave Maximilianea). 8vo. *Mexico* 1865.	The Author.
BÖHM (J. G.) und ALLÉ (M.) Magnetische und meteorologische Beobachtungen zu Prag. Sechsundzwanzigster Jahrgang. 4to. *Prag* 1866.	The Observatory.
BOWLES (G.) Introduccion a la Historia Natural, y a la Geografia Fisica de España. 4to. *Madrid* 1775.	Dr. Sharpey, Sec. R.S.
BRUCK (le Capitaine) Manifeste du Magnétisme du Globe et de l'Humanité. 8vo. *Paris* 1866.	The Author.
BRUHNS (C.) Resultate aus den meteorologischen Beobachtungen angestellt an mehreren Orten im Königreich Sachsen. Erster Jahrgang. 4to. *Leipzig* 1866.	The Author.
CHEVREUL (E., For. Mem. R.S.) Notes Historiques sur la Nature Immédiate de l'Amer de Welter et de l'Amer au Minimum (Acide Picrique et Acide Indigotique). 4to. *Paris* 1864.	The Author.
CLAUSIUS (R.) Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie. 8vo. 1865.	The Author.
COLNET d'HUART (De) Mémoire sur la Théorie de la Chaleur. 8vo. *Luxembourg* 1865.	The Author.
CORNET (F. L.) et BRIART (A.) Note sur la Découverte dans le Hainaut, en dessous des Sables rapportés par Dumont au Système Landénien, d'un Calcaire Grossier avec Faune tertiaire. 8vo. *Bruxelles* 1864.	Mons. Dewalque, by Sir Charles Lyell, Bart.
CRÊMONA (L.) Sulle Trasformazioni Geometriche delle figure piane. Nota II. 4to. *Bologna* 1865.	The Author.
CRESTADORO (A.) Catalogue of the Books in the Manchester Free Library. Reference Department. 8vo. *London* 1864.	Manchester Public Free Libraries Committee.
DAUBENY (C., F.R.S.) A Letter to the Provost of Oriel on University Extension. 8vo. *Oxford* 1865.	The Author.
———— Address to the Members of the Devonshire Association for the Advancement of Science, Literature, and Art, June 28, 1865. 8vo.	————
DAUBRÉE ( ) Expériences synthétiques relatives aux Météorites. (Excerpt from Comptes Rendus.) 4to. *Paris* 1866.	The Author.
DAVIS (J. B.) On Synostotic Crania among Aboriginal Races of Man. 4to. *Haarlem* 1865.	The Author.
DAVY (Dr. John, F.R.S.) Miscellaneous Observations on the Blood. 4to. *Edinburgh* 1865.	The Author.
———— Some Observations on the Cuticle in regard to Evaporation. 4to. *Edinburgh* 1865.	————
DE LA RIVE (A., For. Mem. R.S.) Discours prononcé à l'ouverture de la 49^e session de la Société Helvétique. 8vo. *Genève* 1865.	The Author.
DE MORGAN (Aug.) On Infinity, and on the Sign of Equality. 4to. *Cambridge* 1865.	The Author.
———— A Theorem relating to Neutral Series. 4to. *Cambridge* 1865.	————

Presents.	Donors.
DE MORGAN (Aug.) On the Early History of the Signs + and —. 4to. *Cambridge* 1865.	The Author.
DIRCKS (H.) The Life, Times, and Scientific Labours of the second Marquis of Worcester. (Large paper) 8vo. *London* 1865.	The Author.
DOUGHTY (C. M.) On the Jöstedal-bræ Glaciers in Norway, with some general Remarks. 8vo. *London* 1866.	The Author.
DURAND (A.) La Toscane, Album Pittoresque et Archéologique. Liv. 9, 10, 11. fol. *Paris* 1862.	The Prince Demidoff.
EDMONDS (R.) On Earthquakes, and extraordinary Agitations of the Sea. (Excerpt from Phil. Mag. Jan. 1866.) 8vo. *London* 1866.	The Author.
EDMONDS (T. R.) On the Laws governing Human Mortality, Pressure of Saturated Steam, and Density of Saturated Steam. 8vo. *London* 1866.	The Author.
———— On the Law of Human Mortality expressed by a new formula. (Excerpt from Phil. Mag.) 8vo. *London* 1866.	————
EDWARDS (G. N.) and WILLETT (A.) Statistical Tables of the Patients under treatment in the Wards of St. Bartholomew's Hospital during 1865. 8vo. *London* 1866.	The Hospital.
ELLERO (Pietro) Sul Tema proposto dall Regia Academia di Scienze, Lettere ed Arti in Modena, "Dei mezzi più opportuni a bandire dalla società il Duello, o almeno a renderlo meno frequente," Dissertazione. 8vo. *Modena* 1865.	The Author.
FARRAR (Rev. F. W., F.R.S.) Chapters on Language. 8vo. *London* 1865.	The Author.
FERGUSSON (E. F. T.) and SEARLE (W. L.) Magnetical and Meteorological Observations made at the Government Observatory, Bombay, in the year 1863. 4to. *Bombay* 1864.	H. M. Indian Government.
FORBES (J. D., F.R.S.) Experimental Inquiry into the Laws of the Conduction of Heat in Bars, and into the Conducting Power of Wrought Iron. 2 parts. 4to. *Edinburgh* 1862–65.	The Author.
FRAUENFELD (G. von) Das Vorkommen des Parasitismus im Thier- und Pflanzenreiche. 8vo. *Wien* 1864.	The Author.
GAIRDNER (W. T.) A Plea for an extension and alteration of the Curriculum of Arts in the University of Glasgow. 8vo. *Glasgow* 1865.	The Author.
GARRIGOU (F.) Études sur les Crânes de la Caverne de Lombrives. 8vo. *Paris* 1865.	The Author.
———— Étude Comparative des Alluvions Quaternaires Anciennes et des Cavernes a Ossements des Pyrénées et de l'Ouest de l'Europe. 8vo. *Toulouse* 1865.	————
GAUDIN (A.) Réforme de la Chimie Minérale et Organique, de la Morphogénie Moléculaire et de la Cristallogénie au moyen de la Mécanique des Atomes ou synthèse mathématique. 8vo. *Paris* 1865.	The Author, by A. Claudet, F.R.S.
GEIKIE (A., F.R.S.) The Scenery of Scotland viewed in connexion with its Physical Geology. 8vo. *London* 1865.	The Author.
GRAY (J. E., F.R.S.) Catalogue of Seals and Whales in the British Museum. Second edition. 8vo. *London* 1866.	The Author.
GRIFFIN (J. J.) Chemical Handicraft: a Classified and descriptive Catalogue of Chemical Apparatus. 8vo. *London* 1866.	The Author.
GRIMSHAW (T. W.) On Atmospheric Conditions influencing the prevalence of Typhus Fever. 8vo. *Dublin* 1866.	The Society.

Presents.	Donors.
GRIMSHAW (T. W.) Thermometric Observations in Fever. 8vo. *Dublin* 1866.	The Society.
GRONAU (J. F. W.) Ueber die Anzahl der Glieder in den Summenformeln der arithmetischen, geometrischen und harmonischen Progressionen. 8vo. *Danzig* 1845.	The Author.
———— Ueber die Bewegung schwingender Körper im widerstehenden Mittel, mit Rücksicht auf die Newton'schen Pendelversuche. 4to. *Danzig* 1850.	————
———— Ueber die allgemeine und volle Gültigkeit mathematischer Formeln: Ein Beitrag zur Deutung des Negativen und Imaginären. Theil 1, & Theil 2. Heft 1. 4to. *Danzig* 1857–63.	————
———— Auflösung der kubischen Gleichungen durch trigonometrische Functionen des Kreises und der Hyperbol. 4to. *Danzig* 1861.	————
———— Tafeln für die hyperbolischen Sectoren und für die Logarithmen ihrer Sinus und Cosinus. 4to. *Danzig* 1862.	————
———— Tafeln fur sämmtliche trigonometrische Functionen der cyklischen und hyperbolischen Sektoren. 8vo. *Danzig* 1863.	————
———— Beilage zu den Tafeln. 8vo. *Danzig* 1863.	————
———— Theorie und Anwendungen der hyperbolischen Functionen, vornehmlich Bestimmung des Widerstands-Coefficienten aus Fallversuchen. 8vo. *Danzig* 1865.	————
GUY (W. A., F.R.S.) On the Original and Acquired Meaning of the term "Statistics," and on the proper functions of a Statistical Society. 8vo. *London* 1865.	The Author.
GYLDEN (H.) Neue Berechnung der Siriusparallaxe aus den am Cap der guten Hoffnung angestellten Beobachtungen. 8vo. *St. Petersburg* 1864.	The Author.
HAAST (J.) Report on the Formation of the Canterbury Plains. fol. *Christchurch* 1864.	The Author.
———— Report on the Geological Survey of the Province of Canterbury. fol. *Christchurch* 1864.	————
———— Report on the Head Waters of the River Waitaki. fol. *Christchurch* 1865.	————
HAIDINGER (W., For. Mem. R.S.) Continuation of a Collection of Tracts on Meteorites. Nos. 40–48. 8vo. 1864.	The Author.
HANSTEEN (C., For. Mem. R.S.) Observations de l'Inclinaison Magnétique faites pendant les années 1855 à 1864 à l'Observatoire de Christiania. 8vo. *Bruxelles* 1864.	The Author.
HARRISON (R.) Catalogue of the London Library. 8vo. *London* 1865.	The London Library.
HOEVEN (J. Van der) Philosophia Zoologica. 8vo. *Lugd. Bat.* 1864.	The Author.
———— Beschrijving van Schedels van Inboorlingen der Carolina-Eilanden. 8vo. *Amsterdam* 1865.	————
HOFMANN (A. W., F.R.S.) Introduction to Modern Chemistry, Experimental and Theoretic. 8vo. *London* 1865.	The Author.
HOGG (Jabez) The Microscope: its History, Construction, and Application. 8vo. *London* 1861.	The Author.
———— Elements of Experimental and Natural Philosophy. 8vo. *London* 1861.	————
———— Investigations into the Histological and Pathological Anatomy of the Urethra and glans Penis. 8vo. *London* 1855.	————

Presents.	Donors.
HOGG (Jabez) The Common Truffle. 8vo. *London* 1862.	The Author.
——— Colour Blindness. 8vo. *London* 1863.	———
——— Observations on the Vegetable Parasites infesting the Human Skin. 8vo. *London* 1866.	———
HOGG (John, F.R.S.) On the Roman Imperial and Crested Eagles, 1864. Notes on some Amphibians, 1865. (Excerpts from Ann. & Mag. Nat. Hist.) 8vo.	The Author.
HOPKINS (E.) Terrestrial Magnetism with reference to the Compasses of Iron Ships, their deviation and remedies. 8vo. *London* 1866.	The Author.
HOUGH (G. W.) Description of an Automatic Registering and Printing Barometer. 8vo. *Albany* 1865.	The Author.
HUDSON (F.) Inorganic Chemistry, for Science Classes. 8vo. *London* 1865.	The Author.
HULL (E.) The Coal-Fields of Great Britain: their History, Structure, and Resources. 8vo. *London* 1861.	The Author.
——— The Geology of the Country around Cheltenham. 8vo. *London* 1857.	———
——— The Geology of the Leicestershire Coal-Field. 8vo. *London* 1860.	———
——— The Geology of the Country around Bolton-le-Moors, Lancashire. 8vo. *London* 1862.	———
——— On the Vestiges of Extinct Glaciers in the Lake Districts of Cumberland and Westmoreland. Part 1. 8vo. *London* 1860.	———
——— On the South-Easterly Attenuation of the Lower Secondary Formations of England. 8vo. *London* 1860.	———
——— On the Vestiges of Extinct Glaciers in the Highlands of Great Britain and Ireland. 8vo. *Manchester* 1861.	———
——— On the New Red Sandstone and Permian Formations as sources of Water-supply for Towns. 8vo. *London* 1864.	———
——— On the Millstone-Grit of North Staffordshire and the adjoining parts of Derbyshire, Cheshire, and Lancashire. 8vo. *London* 1864.	———
JELINEK (P. C.) Die Auflösung der höheren numerischen Gleichungen mit besonderer Rücksicht auf die imaginären Wurzeln nach einer neuen Methode dargestellt. 8vo. *Leipzig* 1865.	The Author.
JEVONS (W. S.) The Coal Question: an Inquiry concerning the progress of the Nation and the probable exhaustion of our Coal-Mines. 8vo. *London* 1865.	The Author.
JOURNALS:—	
Bulletin de Statistique Municipale. Janvier–Décembre 1865. 4to. *Paris.*	The Prefect of the Seine
Cosmos. June to December 1865; January to June 1866. 8vo. *Paris.*	The Editor.
Les Mondes. June to December 1865; January to June 1866. 8vo. *Paris.*	The Editor.
Notes and Queries. June to December 1865; January to June 1866. 4to. *London.*	The Editor.
Revista Brazileira, Jornal de Sciencias, Lettras e Artes, dirigido por Candido Baptista de Oliveira. Numero 1, 3, 4, 6, 7, 8, 10. 8vo. *Rio de Janeiro* 1857–61.	J. Miers, F.R.S.
Symons's Monthly Meteorological Magazine. No. 4. 8vo. *London* 1866.	The Editor.
The American Journal of Science and Arts. Nos. 118, 119, 120, 122. 8vo. *New Haven* 1865–66.	The Editors.
The Athenæum. June to December 1865; January to May 1866. 4to. *London.*	The Editor.
The Builder. July to December 1865; January to June 1866. folio. *London.*	The Editor.

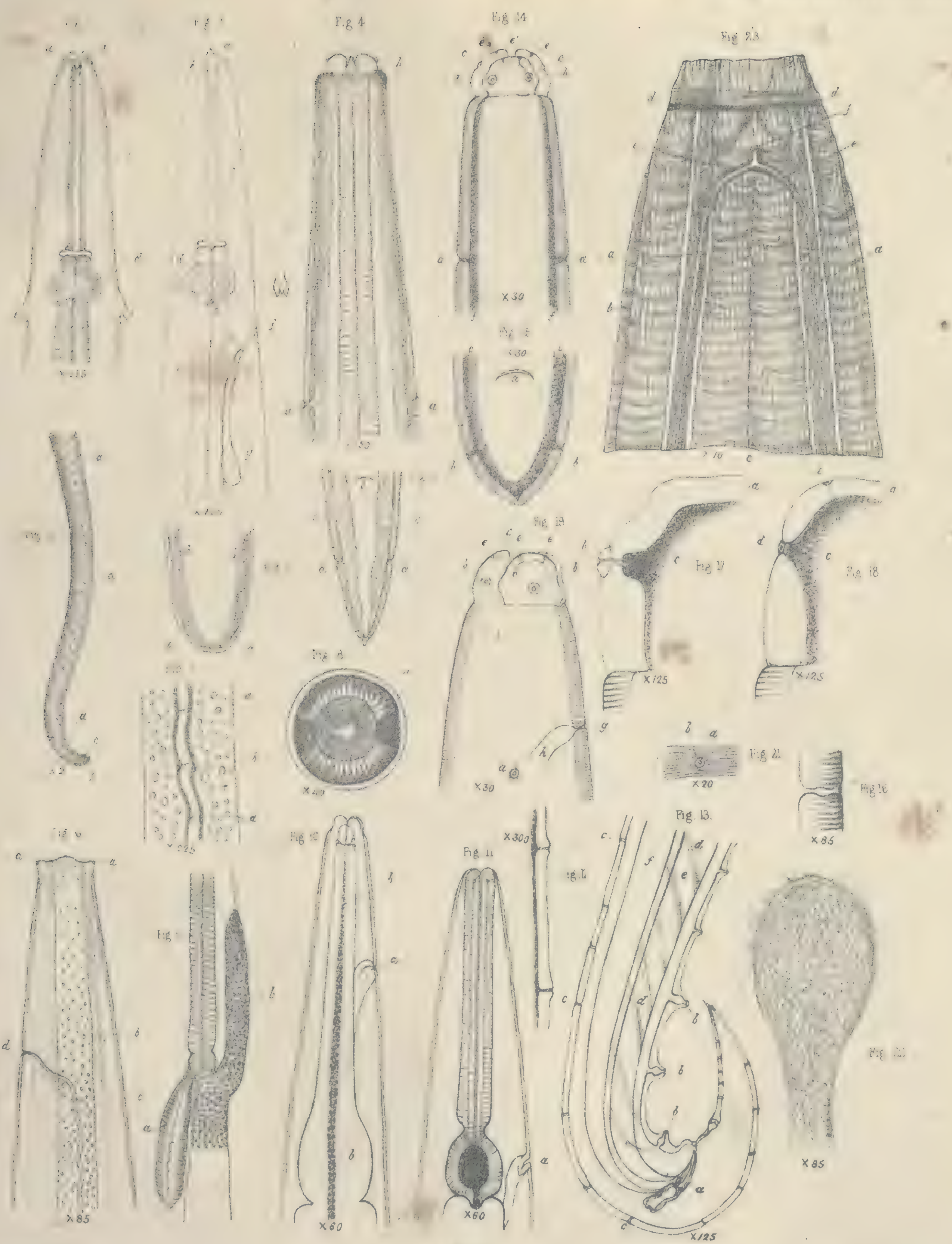
Presents.	Donors.
JOURNALS (*continued*).	
The Chemical News. July to December 1865; January to June 1866. 4to. *London.*	The Editor.
The Educational Times. July to December 1865; January to June 1866. 4to. *London.*	The Editor.
The Geological and Natural History Repertory; edited by S. J. Mackie. Nos. 1–3, 8–14, & part 1. 8vo. *London* 1865–66.	The Editor.
The London Review. July to December 1865; January to June 1866. folio. *London.*	The Editor.
The Philosophical Magazine. July to December 1865; January to June 1866. 8vo. *London.*	W. Francis, Esq.
The Quarterly Journal of Science. Nos. 7–10. 8vo. *London* 1865–66.	The Editors.
The Reader. July to December 1865; January to June 1866. folio. *London.*	The Editor.
Zeitschrift für Biologie, von L. Buhl, M. Pettenkofer, L. Radlkofer, C. Voit. Band I. Hefte 1–4; Band II. Heft 1. 8vo. *München* 1865–66.	The Editors.
KLINKERFUES (W.) Fernere Mittheilungen über den Einfluss der Bewegung der Lichtquelle auf die Brechbarkeit eines Strahles. (Excerpt from Göttingen Nachrichten.) 8vo. 1866.	The Author, by Sir J. F. W. Herschel, Bart., F.R.S.
KNOBLAUCH (H.) Ueber die Diffusion der Wärmestrahlen. (Excerpt from Pogg. Ann.) 8vo. *Berlin* 1865.	The Author.
KOHL (J. G.) Die beiden ältesten General-Karten von Amerika; ausgeführt in den Jahren 1527 und 1529 auf Befehl Kaiser Karl's V. im Besitz der Grossherzoglichen Bibliothek zu Weimar. folio. *Weimar* 1860.	General Sabine, P.R.S.
KÖLLIKER (A., For. Mem. R.S.) Icones Histiologicæ oder Atlas der Vergleichenden Gewebelehre. Zweite Abtheilung, erstes Heft. 4to. *Leipzig* 1866.	The Author.
KOPS (J.) en HARTSEN (F. A.) Flora Batava, of Afbeelding en Beschrijving van Nederlandsche Gewassen. Afl. 192–195. Title & Index to Vol. XII. 4to. *Amsterdam.*	H. M. The King of the Netherlands.
KUPFFER (A. T., For. Mem. R.S.) Annales de l'Observatoire Physique Central de Russie, Année 1862. 2 vols. 4to. *St. Pétersbourg* 1865.	The Observatory.
LACERDA (José de) Portuguese African Territories. Reply to Dr. Livingstone's Accusations and Misrepresentations. (Two copies). 8vo. *London* 1865.	The Author.
LAMY (A.) Le Thallium et ses principaux composés. 4to. *Paris* 1865.	The Author.
LANDRIN (Armand) Coquilles Nouvelles. 8vo. *Versailles* 1864.	The Author.
———— Notice historique et analytique sur les Travaux relatifs à la Coloration des Végétaux. 8vo. *Versailles.*	————
———— Quelques Monstruosités Végétales et Catalogue des Cas de Proliférie observés par A. L. 8vo. *Versailles* 1865.	————
———— Lettres de La Quintynie sur la Culture des Melons, traduites de l'Anglais. 8vo. *Versailles.*	————
LARTET (E.) and CHRISTY (H.) Reliquiæ Aquitanicæ; being Contributions to the Archæology and Palæontology of Périgord and the adjoining Provinces of Southern France. Parts 1 & 2. 4to. *London*, 1865–66.	The Executors of the late H. Christy, Esq.
LEIDY (J.) Cretaceous Reptiles of the United States. 4to. *Philadelphia* 1865.	The Author.
LLOYD (Rev. Dr., F.R.S.) Observations made at the Magnetical and Meteorological Observatory at Trinity College, Dublin. Vol. I. 1840–1843. 4to. *Dublin* 1865.	The College.

Presents.	Donors.
LOVÉN (S.) Om Österjön. 8vo. *Stockholm* 1864.	The Author.
LOWE (E. J.) Our Native Ferns and their Varieties. Part 21. 8vo *London.*	The Author.
M'DONNELL (R., F.R.S.) Observations on the Functions of the Liver. 8vo. *Dublin* 1865.	The Author.
MAIN (Rev. R., F.R.S.) Astronomical and Meteorological Observations made at the Radcliffe Observatory, Oxford, in the year 1863. Vol. XXIII. 8vo. *Oxford* 1866.	The Radcliffe Trustees.
MAKENAUER (E.) Urzeugung (generatio äquivoca) durch Condensirung elektrischer Auflösungen aus Prof. P. T. Meissner's Wärmelehre. 8vo. *Wien* 1865.	The Author.
———— Planeten, Monde und Meteore. 8vo. *Wien* 1865.	————
MALAISE (C.) Sur les Silex ouvrés de Spiennes. 8vo. *Bruxelles* 1866.	The Author.
MAP, PORTRAITS, &c.:—	
Map of Spitzbergen, by N. Dunér and A. E. Nordenskiöld, with Explanatory Remarks. 8vo. *Stockholm* 1865.	Dr. O. Torell.
Meteorological Diagram showing the daily elements throughout the year 1865 in London, by C. O. F. Cator.	Mr. E. Stanford.
Photographic Portraits of Sir Wm. Fergusson, F.R.S., Sir J. Ranald Martin, F.R.S., and Erasmus Wilson, F.R.S., by Wilson and Beadell.	The Photographers.
Thirty-six Photographic Portraits of Members of the Literary and Scientific Portrait Club. (In a portfolio.)	Messrs. Maull & Co.
MARTH (A.) Auxiliary Tables for the Solution of Lambert's Equation, with a few Remarks on the Determination of Cometary Orbits. 4to. *London* 1865.	The Author.
MARTINS (C.) La Végétation du Spitzberg comparée à celle des Alpes et des Pyrénées. 4to. *Montpellier* 1865.	The Author.
———— Du Spitzberg au Sahara, Étapes d'un Naturaliste au Spitzberg, en Laponie, en Suisse, en France, en Italie, en Orient, en Egypte, et en Algérie. 8vo. *Paris* 1866.	————
———— Sur la possibilité d'atteindre le Pôle Nord. 8vo. *Paris* 1866.	————
MAUGIERI (P. A.) Corso di Filosofia Razionale ossia psiche-ontologico. Vol. I. 8vo. *Catania* 1865.	The Author.
MELSENS ( ) Mémoire sur l'emploi de l'Iodure de Potassium, pour combattre les Affections saturnines, mercurielles et les Accidents consécutifs de la Syphilis. 8vo. *Bruxelles* 1865.	The Author.
MIQUEL (F. A. G.) Annales Musei Botanici Lugduno-Batavi. Tom. II. fasc. 1 & 2. fol. *Amst.* 1865.	The Editor.
MOREIRA (Carvalho) Relatorio sobre a Exposição Internacional de 1862. 4to. *Londres* 1863.	J. Miers, F.R.S.
———— Atlas do Relatorio Brasileiro. 4to.	————
MORGAN (J. E.) The Danger of Deterioration of Race from the too rapid increase of great cities. 12mo. *London* 1866.	The Publishers.
MÜHRY (A.) Supplement zur Klimatographischen Uebersicht der Erde, mit einem Appendix. 8vo. *Leipzig* 1865.	The Society.
MUSETTINIUS (F.) In Honorem Dantis Aligherii Specimen Epigraphicum. 8vo. *Massæ Carrariæ* 1865.	The Author.
NAGY (K.) Die Sonne und die Astronomie. 8vo. *Leipzig* 1866.	The Author.
NAMIAS (Giacinto) Considerazioni Mediche risguardanti le acque di Recoaro. 8vo. *Venezia* 1864.	The Author.

Presents.	Donors.
NAMIAS (Giacinto) Della Infezione marciosa del Sangue (Pyæmia) Considerazioni. 8vo. *Venezia* 1865.	The Author.
———— Nuovi Studii Esperimentali d'Elettricità nelle sue applicazioni alla Medicina. 4to. *Venezia* 1865.	————
NOBLE (W. H.) Second Report on Ballistic Experiments. 8vo. *London* 1865.	The Author.
PICTET (A. E.) Synopsis des Névroptères d'Espagne. 8vo. *Genève* 1865.	The Author.
PLANTAMOUR (E.) Résumé Météorologique de l'Année 1864 pour Genève et le Grand St. Bernard. 8vo. *Genève* 1865.	The Author.
———— Recherches sur la Distribution de la Température à la surface de la Suisse pendant l'hiver 1863–64. 8vo. *Genève* 1865.	————
PLATEAU (F.) Sur la Force musculaire des Insectes. 8vo.	The Author, by Prof. Tyndall, F.R.S.
POUDRA ( ) Perspective—Relief. 8vo. *Paris* 1866.	The Author.
PRATT (Rev. J. H., F.R.S.) A Treatise on Attractions, Laplace's Functions, and the Figure of the Earth. 8vo. *London* 1865.	The Author.
PRICE (Rev. B., F.R.S.) A Treatise on the Infinitesimal Calculus. Vol. II. 8vo. *Oxford* 1865.	The Author.
QUETELET (A., For. Mem. R.S.) Histoire des Sciences Mathématiques et Physiques chez les Belges. 8vo. *Bruxelles* 1864.	The Author.
———— Observations des Phénomènes Périodiques des Plantes et des Animaux pendant les Années 1861 et 1862. 4to. *Bruxelles.*	————
———— Annuaire de l'Observatoire Royal de Bruxelles, 1865. 12mo. *Bruxelles* 1864.	————
———— et HEUSCHING (X.) Statistique Internationale (Population), publiée avec la collaboration des Statisticiens Officiels des différents États de l'Europe et des États Unis d'Amérique. 4to. *Bruxelles* 1865.	The Authors.
————, LINSTER, et FRITSCH (C.) Sur les Époques comparées de la Feuillaison et de la Floraison à Bruxelles, à Stettin et à Vienne. 8vo. *Bruxelles.*	The Authors.
QUETELET (E.) Sur l'État de l'Atmosphère à Bruxelles pendant l'Année 1865. 8vo. *Bruxelles* 1866.	The Author.
———— Note sur l'état de l'Atmosphère à Bruxelles pendant l'Année 1864. 8vo. *Bruxelles.*	————
RANKINE (W. J. M., F.R.S.) On Rational Approximations to the Circle. (Excerpt from Phil. Mag.) 8vo. *London* 1865.	The Author.
RAWLINSON (Sir H. C., F.R.S.) and NORRIS (E.) A Selection from the Miscellaneous Inscriptions of Assyria. folio. *London* 1866.	The Trustees of the British Museum.
RESLHUBER (A.) Resultate aus den im Jahre 1864 auf der Sternwarte zu Kremsmünster angestellten meteorologischen Beobachtungen. 8vo. *Linz* 1865.	The Author.
ROWELL (G. A.) An Essay on the Cause of Rain and its allied Phenomena. 8vo. *Oxford* 1859.	The Author.
RUDOLPHI (C. A.) Recentioris Ævi Numismata Virorum de Rebus Medicis et Physicis Meritorum Memoriam servantia collegit et recensuit C. A. R. 8vo. *Berolini* 1829.	Dr. Sharpey, Sec. R.S.
RUSSELL (J. Scott, F.R.S.) The Modern System of Naval Architecture. 3 vols. folio. *London* 1865.	The Author.

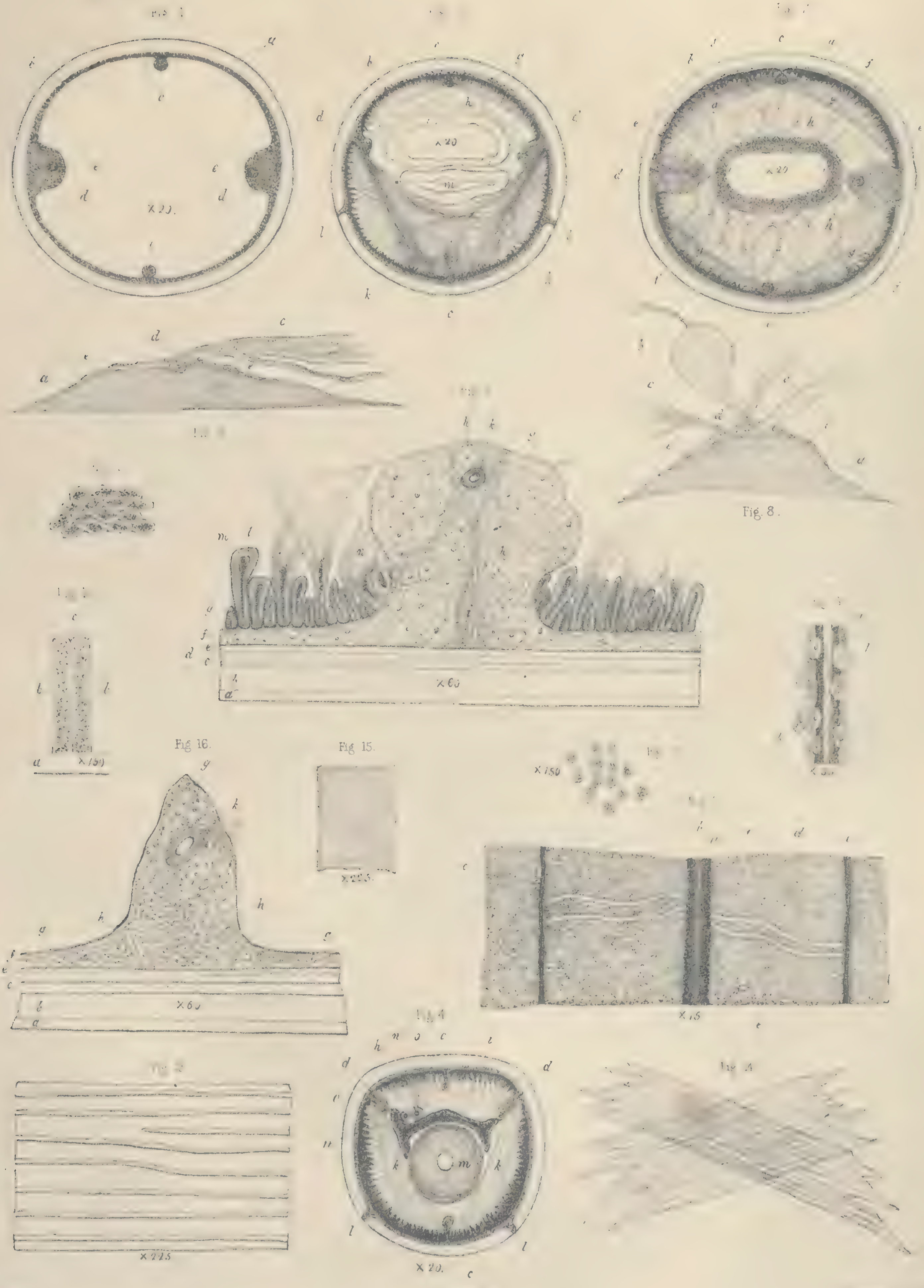
Presents.	Donors.
RYAN (M.) The celebrated Theory of Parallels, Demonstration of the celebrated Theorem Euclid I. Axiom 12. 8vo. *Washington* 1866.	The Author.
SALISBURY (R. A.) The Genera of Plants. A Fragment containing part of Liriogamæ. [Edited by Dr. J. E. Gray, F.R.S.] 8vo. *London* 1866.	The Editor.
SALVIATI (A.) On Mosaics (generally), and the superior advantages, adaptability, and general use in the past and present age in Architectural and other Decorations of Enamel Mosaics. 8vo. *London* 1865.	The Author.
SAN-GERMAN (L.) Ensayos para utilizar como Fuerza motriz el Calor y la Presion atmosférica. 8vo. *Barcelona* 1866.	The Author.
SCHEFFLER (H.) Die Physiologische Optik: Eine Darstellung der Gesetze des Auges. 2 vols. 8vo. *Braunschweig* 1865.	The Author.
SCHLAGINTWEIT-SAKÜNLÜNSKI (H. de), SCHLAGINTWEIT (A. and R. de) Results of a Scientific Mission to India and High Asia. Vol. IV. 4to. and Atlas, folio. *Leipzig* 1866.	The Secretary of State for India.
SCOTT (G.) On Systematic Functions of the Natural Numbers, and on their partitions. 8vo. 1865.	The Author.
SIDLER (G.) Ueber die Wurflinie im leeren Raume. 4to. *Bern* 1865.	The Author.
SMYTH (Admiral W. H., F.R.S.) The Cycle of Celestial Objects continued at the Hartwell Observatory to 1859, with a notice of recent discoveries, including details from the Ædes Hartwellianæ. 8vo. *London* 1860.	Dr. Lee, F.R.S.
——————— Sidereal Chromatics; being a reprint, with additions, from the "Bedford Cycle of Celestial Objects," and its "Hartwell Continuation," on the Colours of Multiple Stars. (Large paper) 4to. *London* 1864.	———
STANLEY (W. F.) A Descriptive Treatise on Mathematical Drawing Instruments. 8vo. *London* 1866.	The Author.
STAS (J. S.) Nouvelles Recherches sur les Lois des Proportions Chimiques, sur les Poids Atomiques et leurs Rapports Mutuels. 8vo. *Bruxelles* 1865.	The Author.
STEENSTRUP (J. J. S., For. Mem. R.S.) Geognostisk-Geologisk Undersögelse af Skovmoserne Vidnesdam og Lillemose i det Nordlige Sjelland. 4to. *Kjöbenhavn* 1841.	The Author.
——————— Om Forplantning og Udvikling gjennem vexlende Generationsrækker, en særegen Form for Opfostringen i de lavere Dyrklasser. 4to. *Kjöbenhavn* 1842.	———
——————— Om Hr Professor Worsaaes Tvedeling af Steenalderen. 8vo. *Kjöbenhavn* 1860.	———
——————— Nye Oplysninger om Philichthys Xiphiæ, *Stp.* 8vo. *Kjöbenhavn* 1862.	———
——————— Philichthys Xiphiæ en ny Snylter hos Sværd-fisken. 8vo. *Kjöbenhavn* 1862.	———
——————— Imod Hr. Prof. Worsaaes Tvedeling af Stenalderen. 8vo. *Kjöbenhavn* 1862.	———
——————— Om Skjævheden hos Flynderne og navnlig om Vandringen af det övre Öie fra Blindsiden till Oiesiden tvers igjennem Hovedet m.m. 8vo. *Kjöbenhavn* 1864.	———
——————— Om Flynderslægten Zeugopterus og Bygningen af dens Gjællehulle. 8vo. *Kjöbenhavn* 1865.	———

Presents.	Donors.
STEENSTRUP (J. J. S., For. Mem. R.S.) Et Blik paa Natur- og Öldforskningens Forstudier til Besvarelsen af Spörgsmaalet om Menneskeslægtens tidligste Optræden i Europa. 8vo. *Kjöbenhavn.*	The Author.
——— and LÜTKEN (C. F.) Bidrag til Kundskab om det aabne Havs Snyltekrebs og Lernæer samt om nogle andre nye elle hidtil kun ufuldstændigt kjendte parasitiske Copepoder. 4to. *Kjöbenhavn* 1861.	J. J. Steenstrup, For. Mem. R.S.
STRUVE (O.) Observations de quelques Nébuleuses. Observations du satellite de Sirius. 8vo. *St. Pétersbourg* 1864.	The Author.
——— Jahresbericht am 17 Mai 1864, dem Comité der Nicolai-Hauptsternwarte. 8vo. *St. Petersburg* 1864.	———
SYKES (Col. W. H., F.R.S.) Organization, Strength, and Cost of the English and French Navies in 1865. 8vo. *London* 1866.	The Author.
VINCENT (Levinus) Elenchus Tabularum Pinacothecarum atque Nonnullorum Cimeliorum in Gazophylacio L. V. 4to. *Harlemi Bat.* 1719.	Dr. Sharpey, Sec.R.S.
——— Descriptio Pipæ seu Bufonis Aquatici Surinamensis fœtus enitentis in dorso, unde videntur prodire, addita Descriptione Ranarum earumque generatione. 4to. *Harlemi* 1726.	———
——— Catalogus et Descriptio Animalium Volatilium, Reptilium et Aquatilium. 4to. *La Haye* 1726.	———
VIQUESNEL (A.) Coup d'Œil sur quelques points de l'Histoire Générale des Peuples Slaves et de leurs Voisins les Turcs et les Finnois. 8vo. *Lyon* 1865.	The Author, by Sir R. I. Murchison, Bart.
WAGNER (A.) Ueber den Gang der Pulkowaer Normaluhr. 8vo. *St. Petersburg* 1864.	The Author.
WALLON (H.) Richard II. Épisode de la Rivalité de la France et de l'Angleterre. 2 vols. 8vo. *Paris* 1864.	The Author.
WATTS (H.) A Dictionary of Chemistry. Parts 27–34. 8vo. *London* 1865–66.	The Editor.
WEST (L. v.) Eine dringende Mahnung an Freunde der Physik, Mechanik und Astronomie zur Abwehr einer für jene Wissenschaften gemeinsamen Gefahr. 8vo. *Wien* 1866.	The Author.
WHEATLEY (H. B.) Chronological Notices of the Dictionaries of the English Language. 8vo. *London* 1866.	The Author.
WILLIAMS (A.) Report on the Origin, Propagation, Nature, and Treatment of the Cattle Plague. fol. *London* 1866.	The Veterinary Department of the Privy Council Office.
WINKLER (T. C.) Musée Teyler. Catalogue Systématique de la Collection Paléontologique. Quatrième Livraison. 8vo. *Harlem* 1865.	The Author.
WINLOCK (J.) Tables of Mercury for the use of the American Ephemeris and Nautical Almanac. 4to. *Washington* 1864.	The Author.

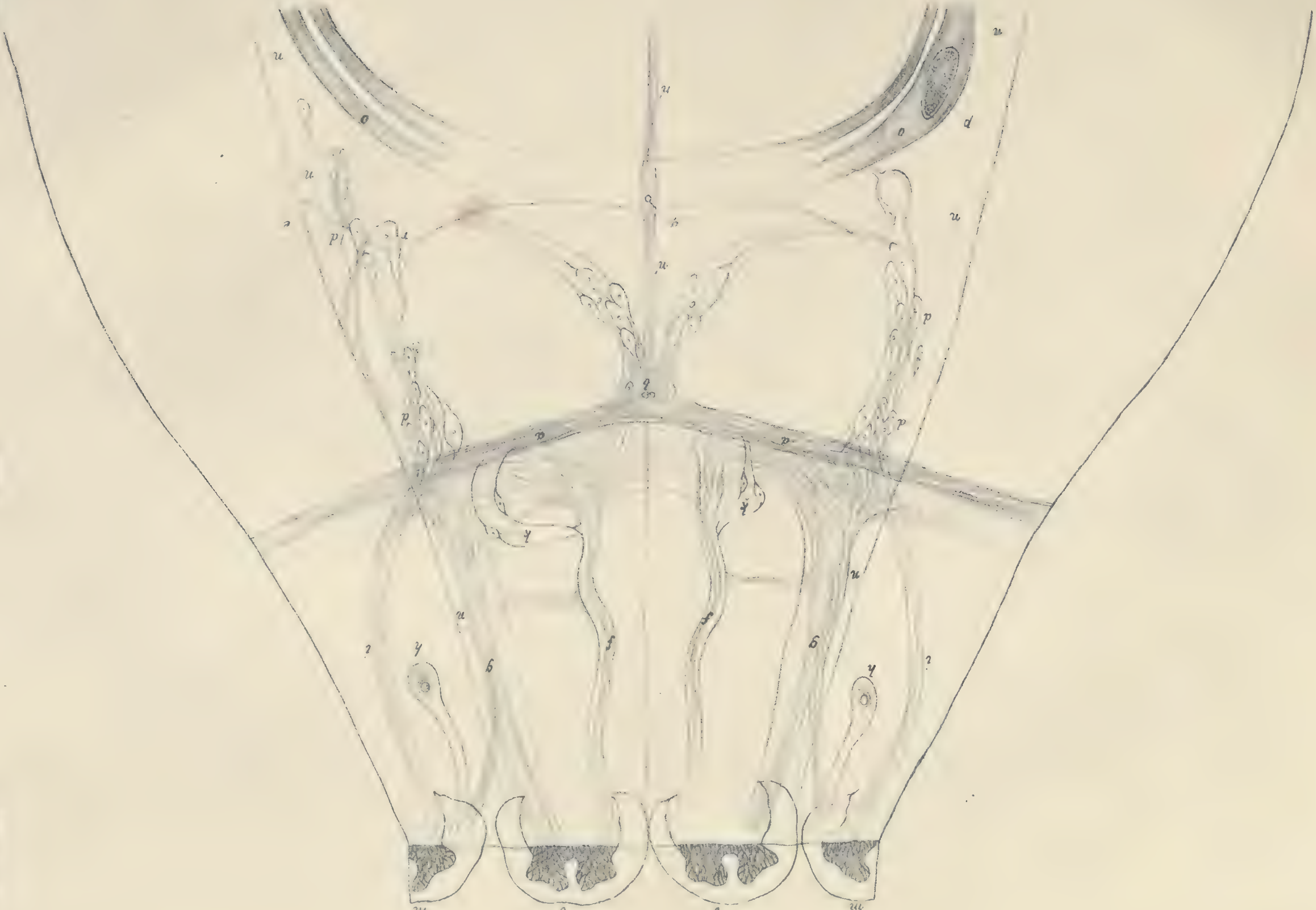


H. C. Bastian del. J. Basire Lith. M. Williams F.L.S.

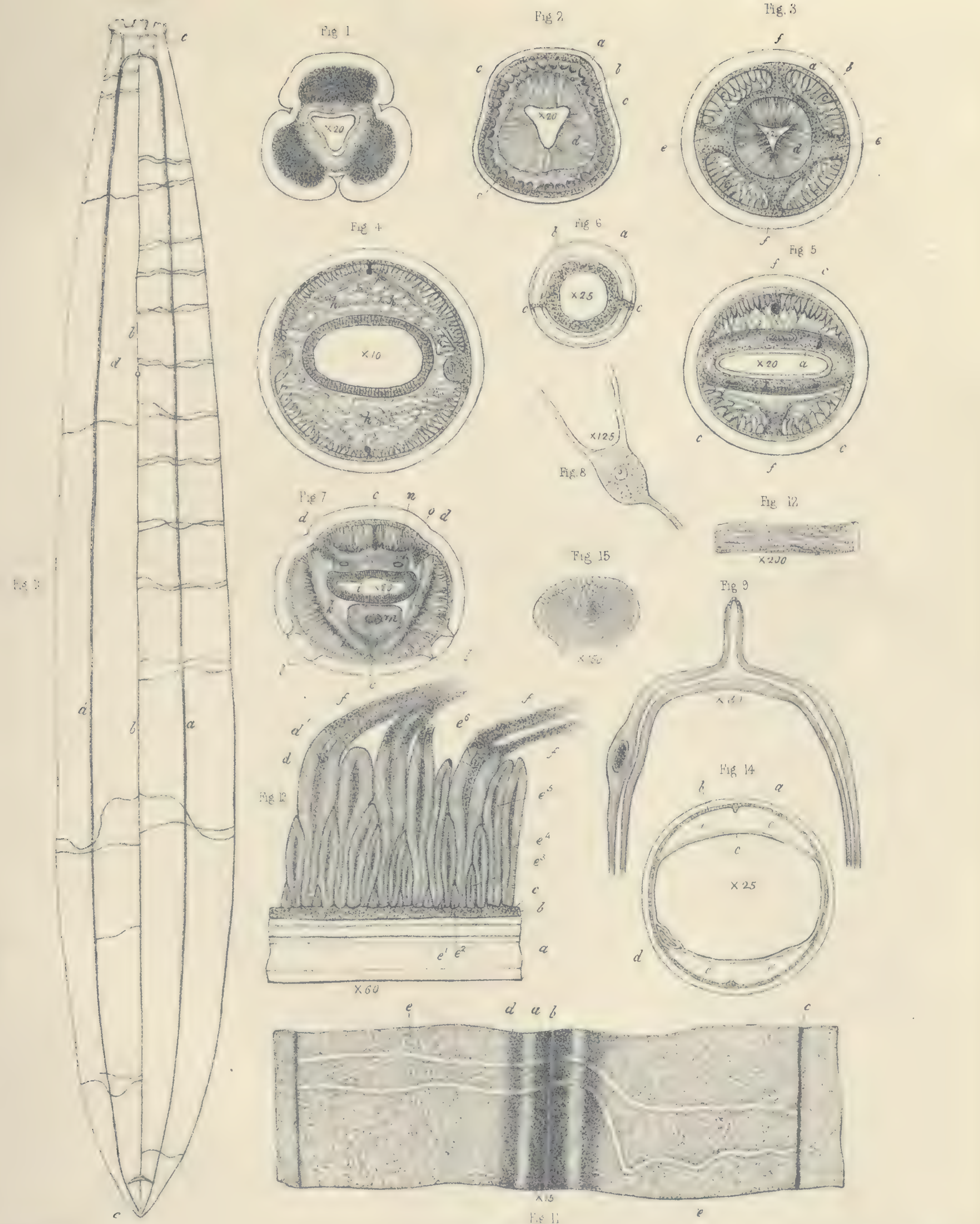
Anatomy of Nematoids Parasitic and Free



F. M. Williams F.L.S. F.Z.S. lith.



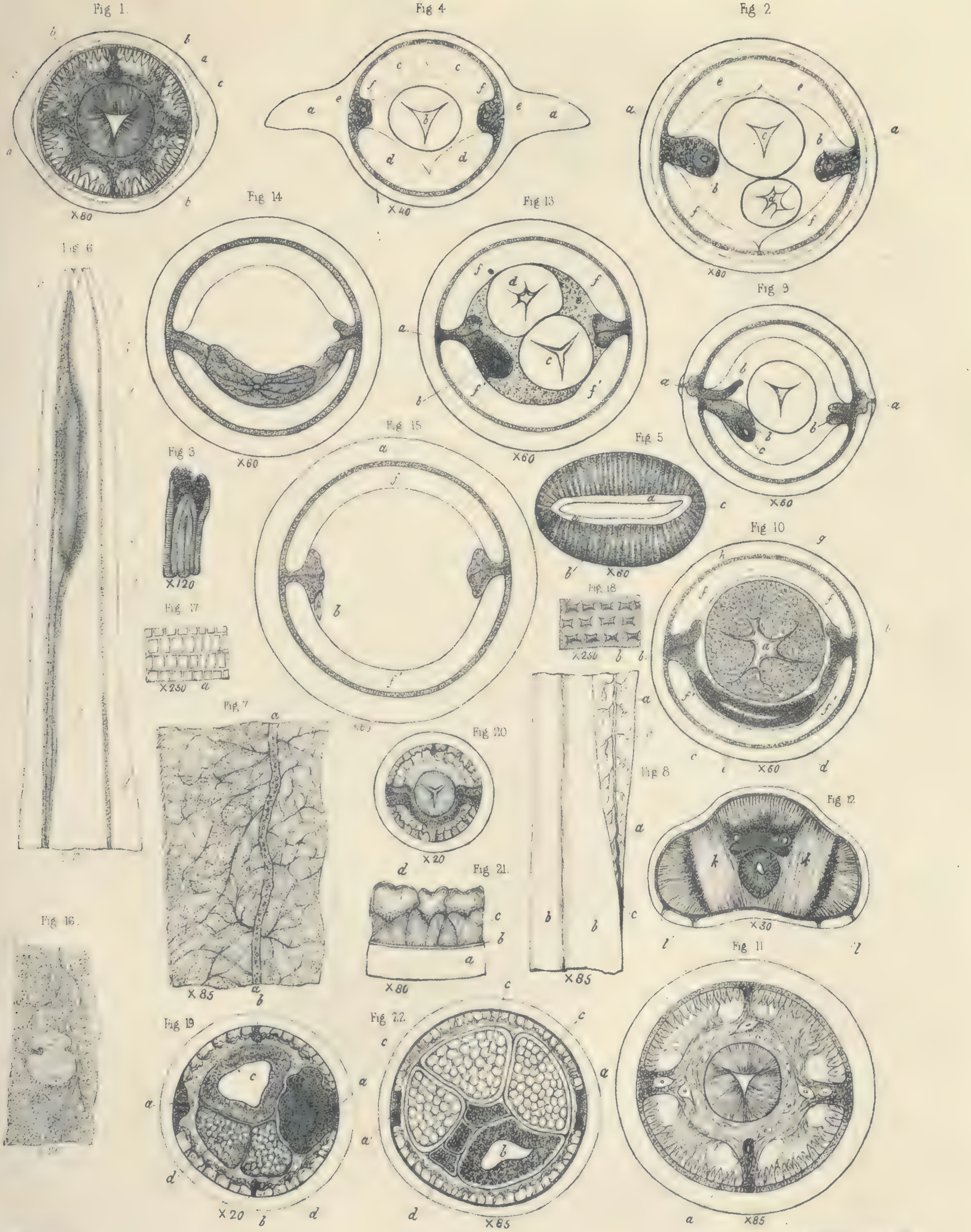
[illegible] [illegible] [illegible] del.



J. Basire sc.

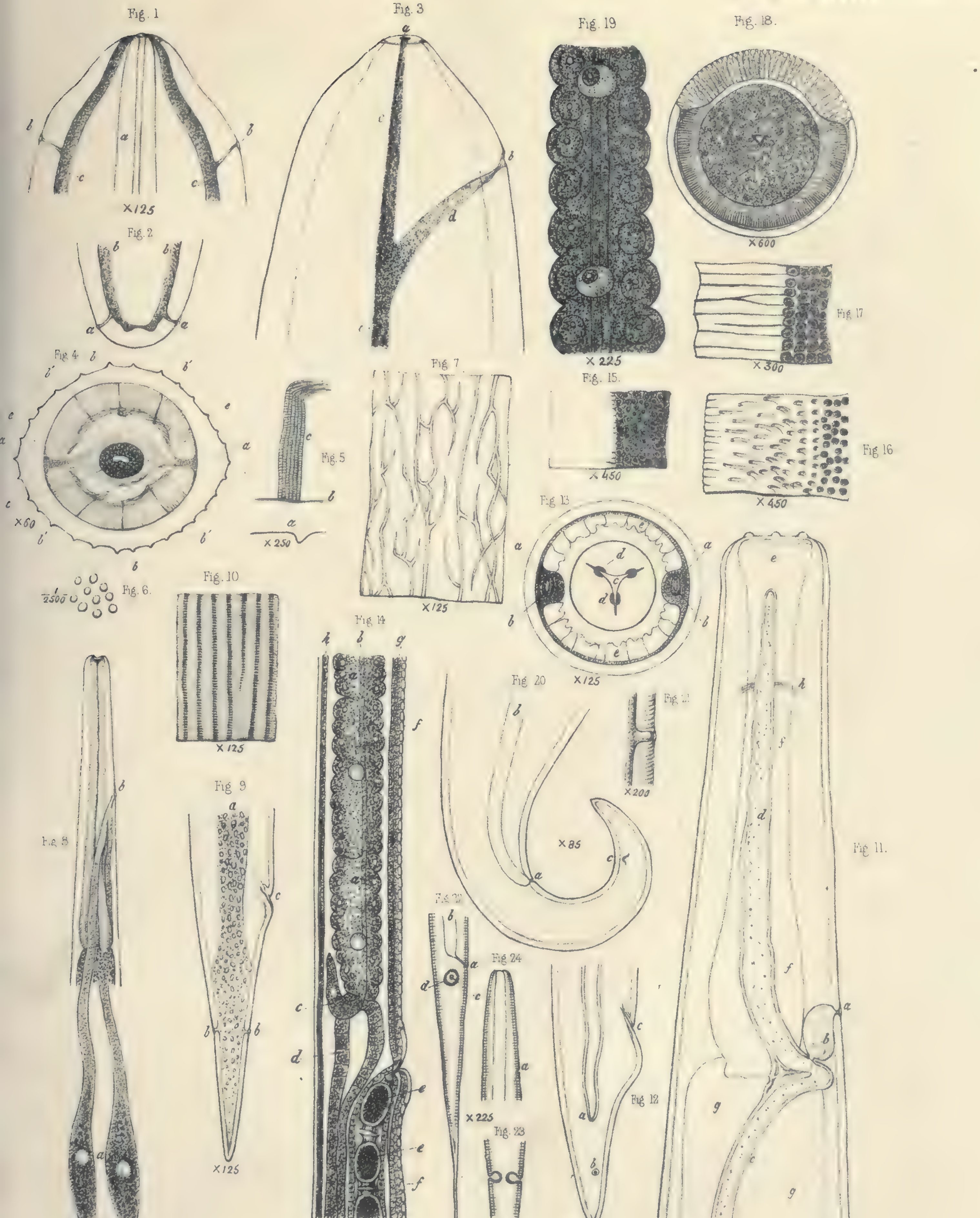
E.M. Williams F.L.S. F.G.S.

Anatomy of Nematoids, Parasitic and Free.



J. C. Bastian del.   J. Basire lith.   W. West imp.

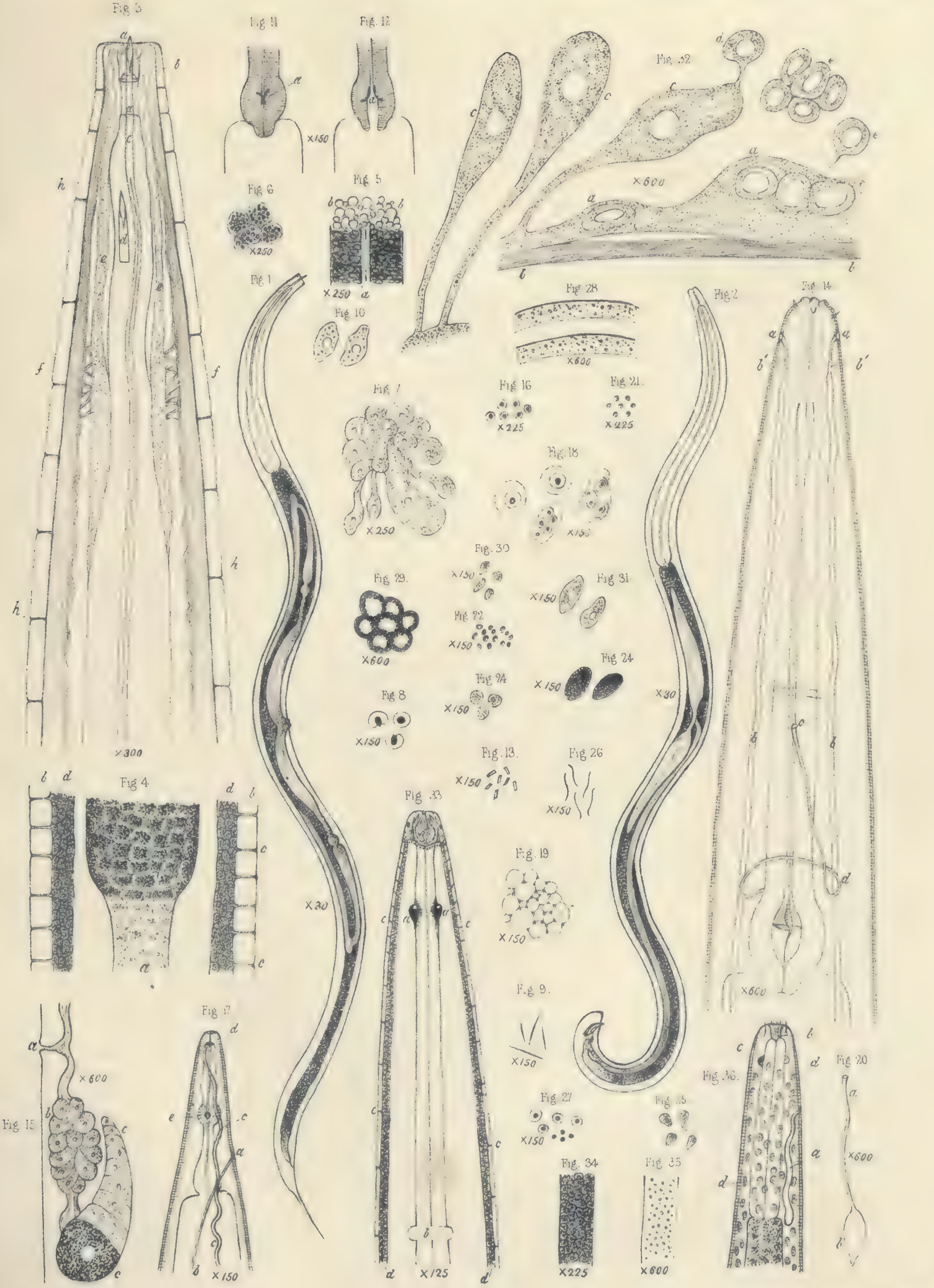
Anatomy of Nematoids, Parasitic and Free.



H. C. Bastian del.

J. Basire lith.

Anatomy of Nematoids, Parasitic and Free.



H.C. Bastian del. J. Basire lith. [illegible]

Anatomy of Nematoids, Parasitic and Free.

GYROMETRIC GOVERNOR.

FOR STEAM ENGINES

Fig. 2.

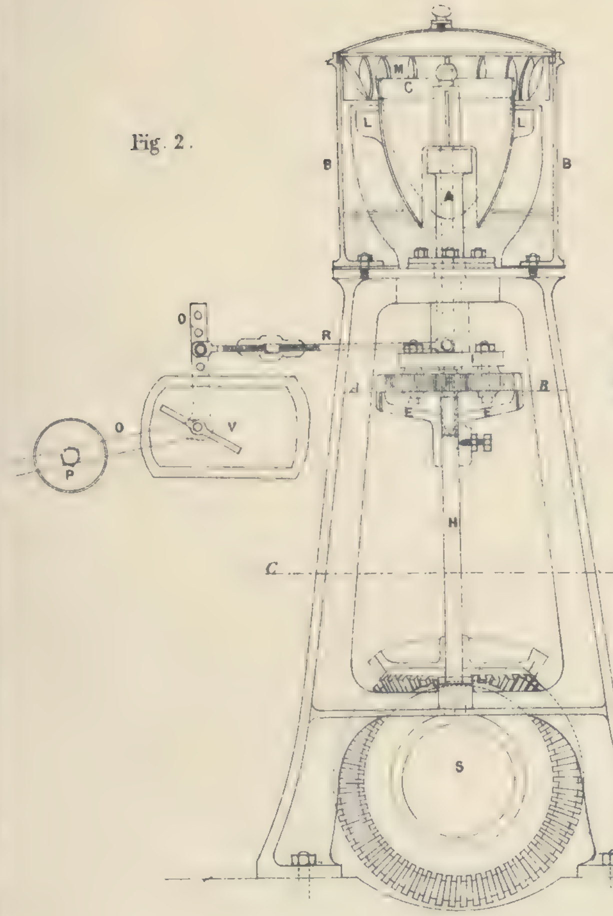
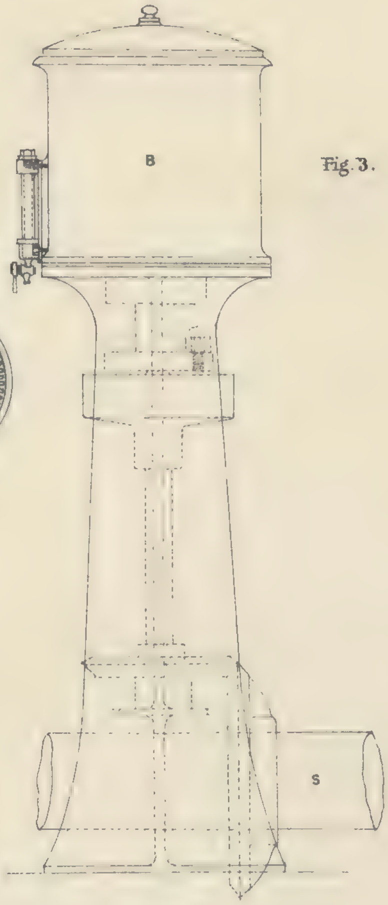


Fig. 3.



Plan of differential Gearing at A.B.

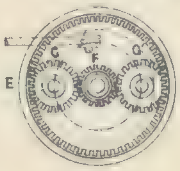


Fig. 4.

Sectional Plan at C.D.

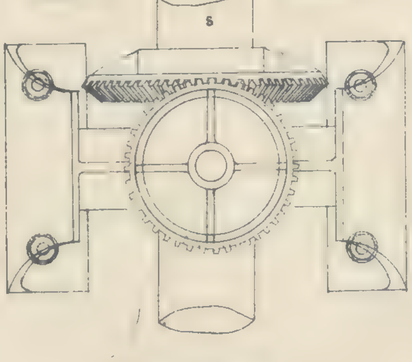
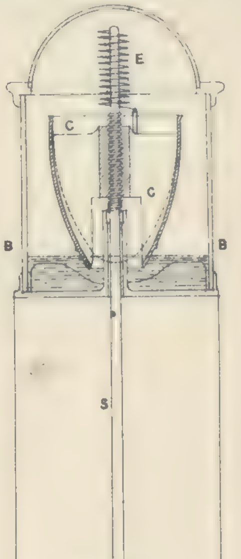


Fig. 5.

Fig. 1.



Plan with cover off shewing Cup.

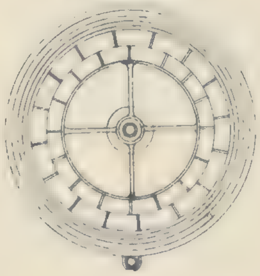


Fig. 6.

SCALE OF INCHES

0 5 10 15 20

J. Basire lith.

ELECTRIC CLOCK.

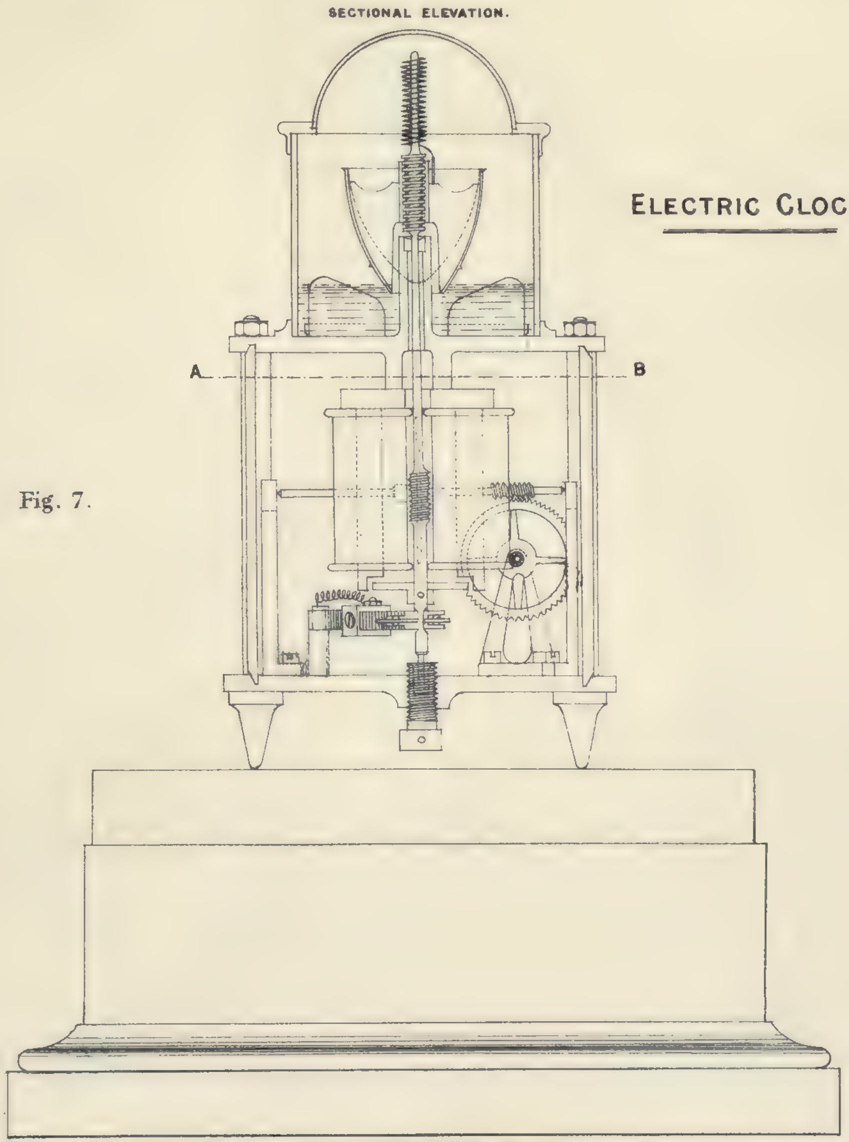


Fig. 7.

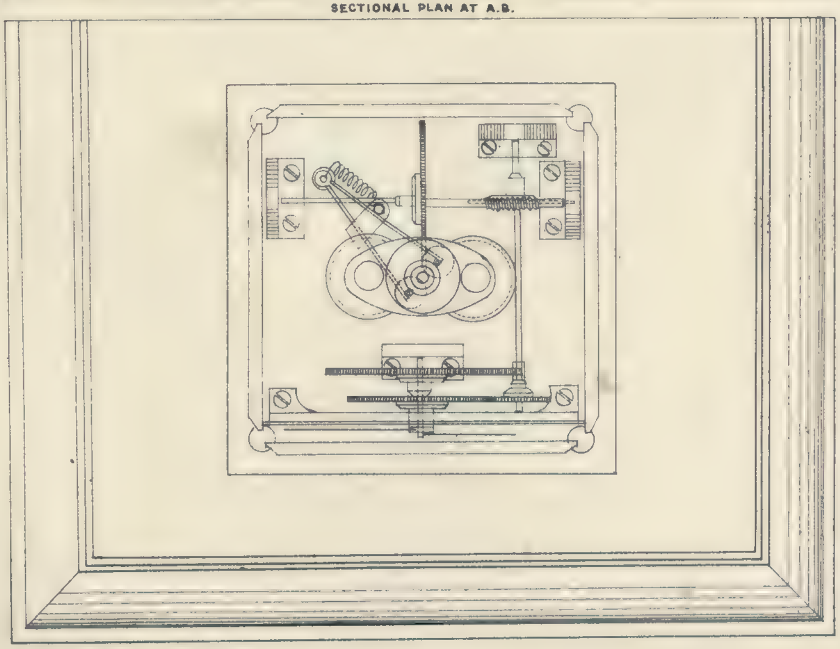
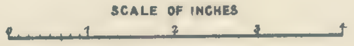
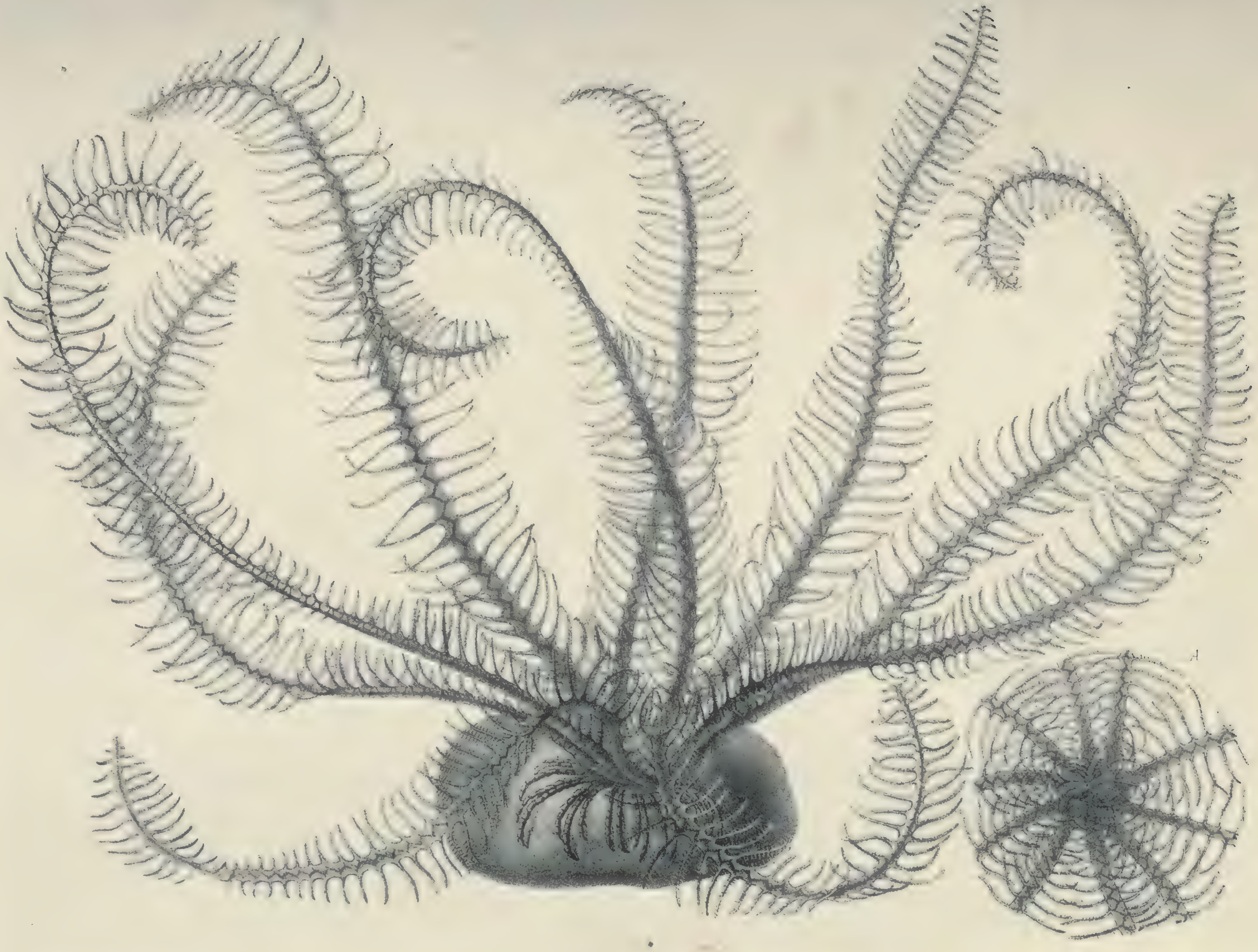


Fig. 8.



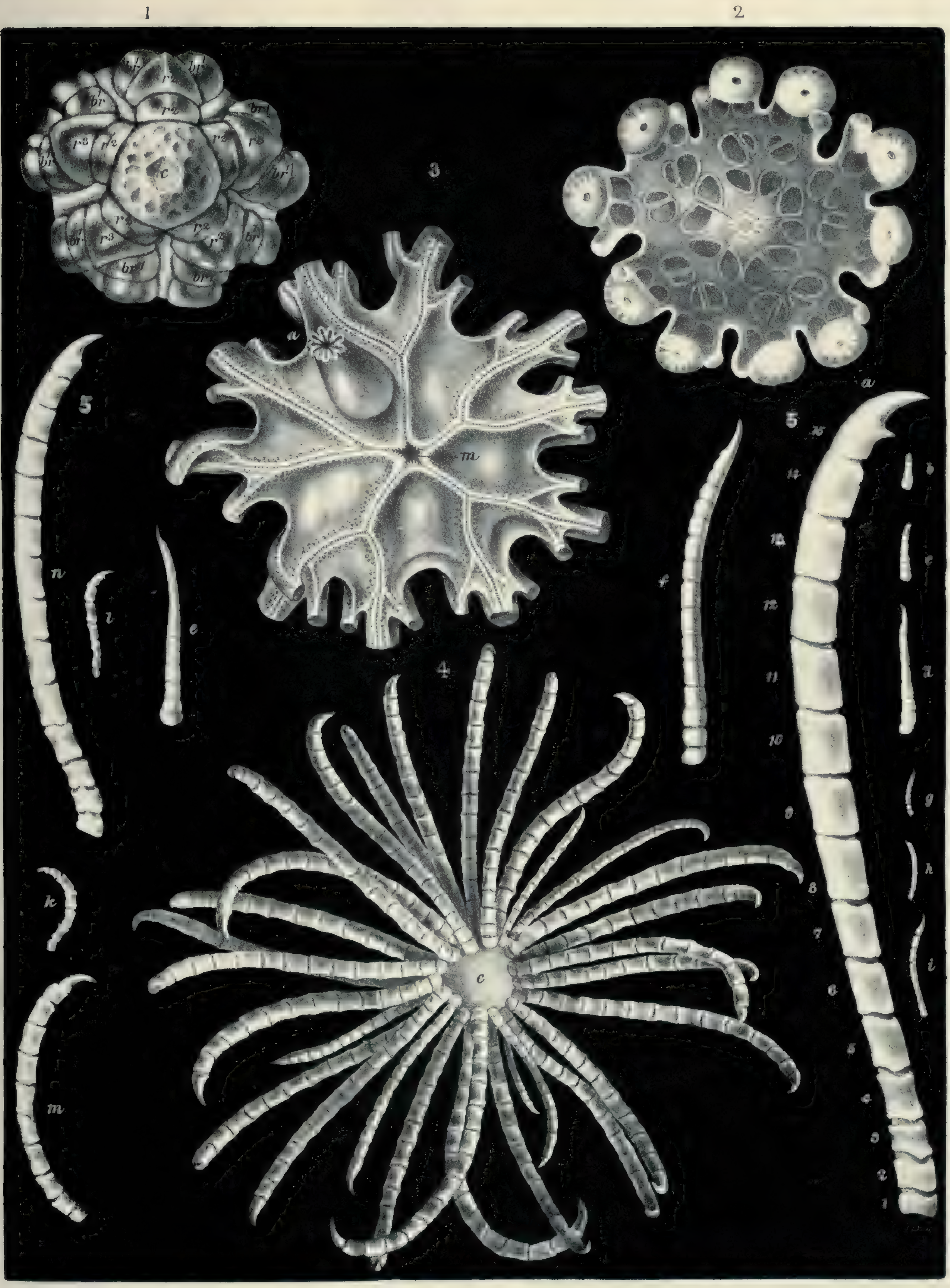
J Basire, lith.



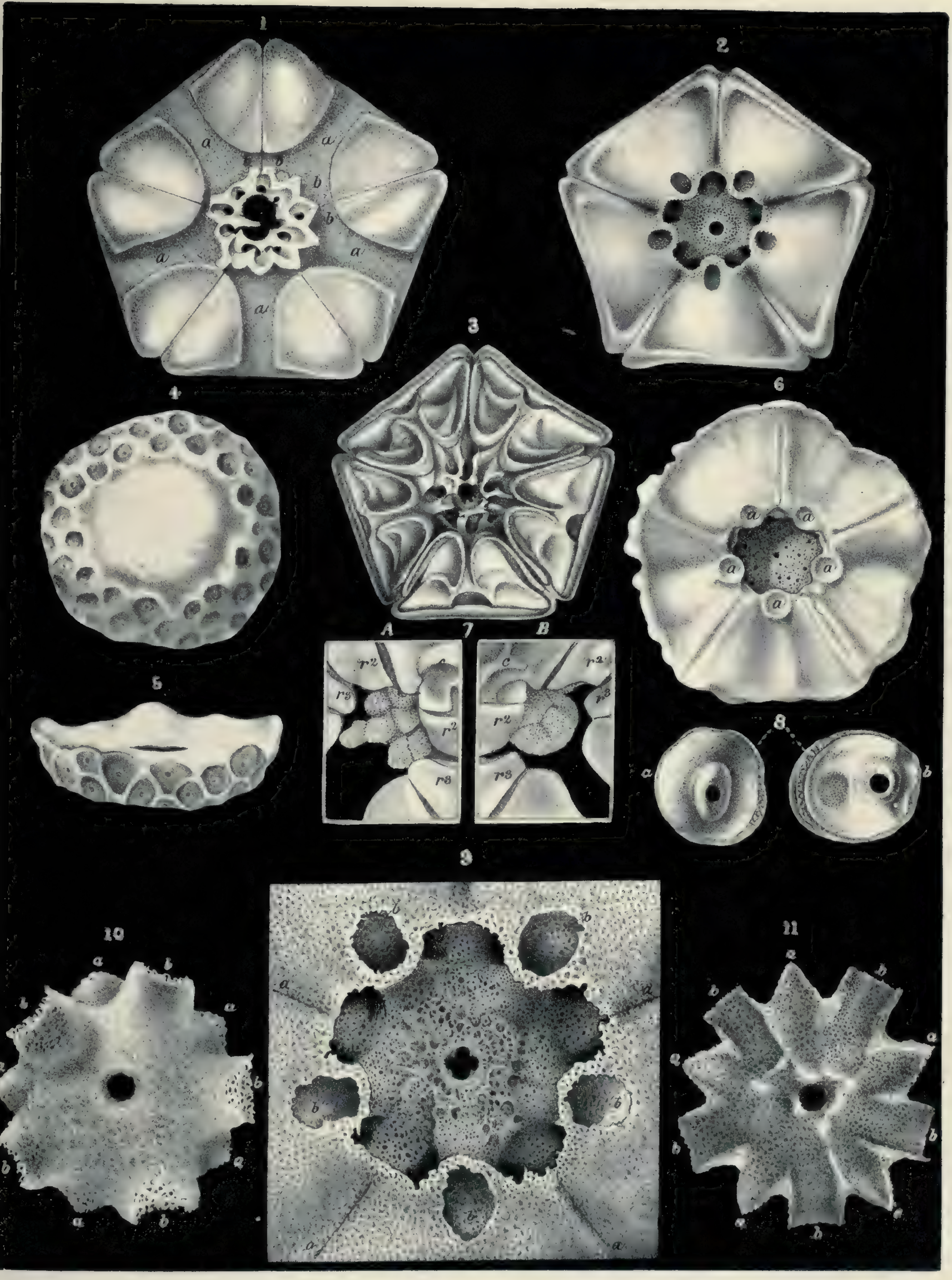
George West [illegible]

Harrison & Sons St Martins Lane

[illegible] lith.



George West del.
Harrison & Sons, St Martins Lane
Lens Aldous lith.

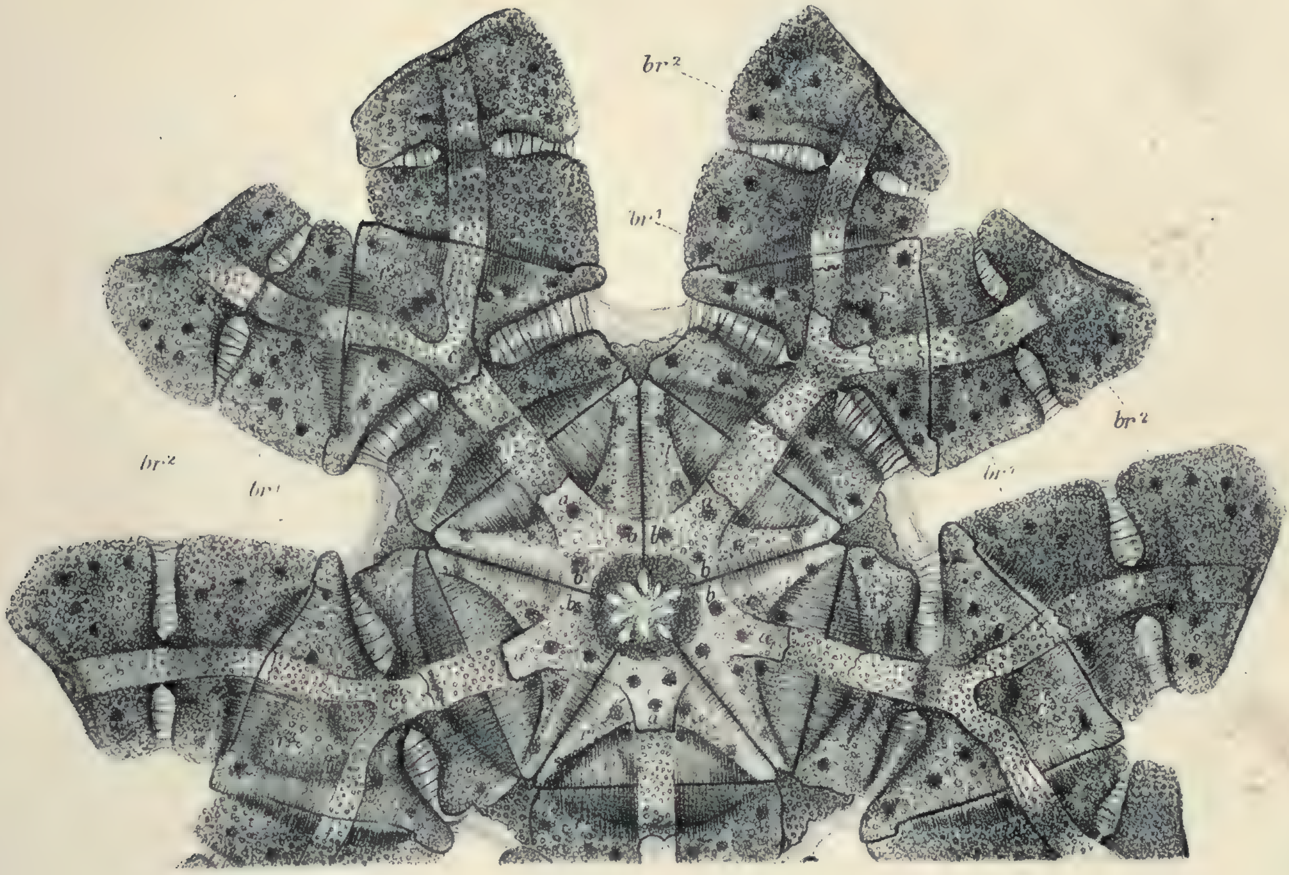


A. H[illegible] and G. West del.

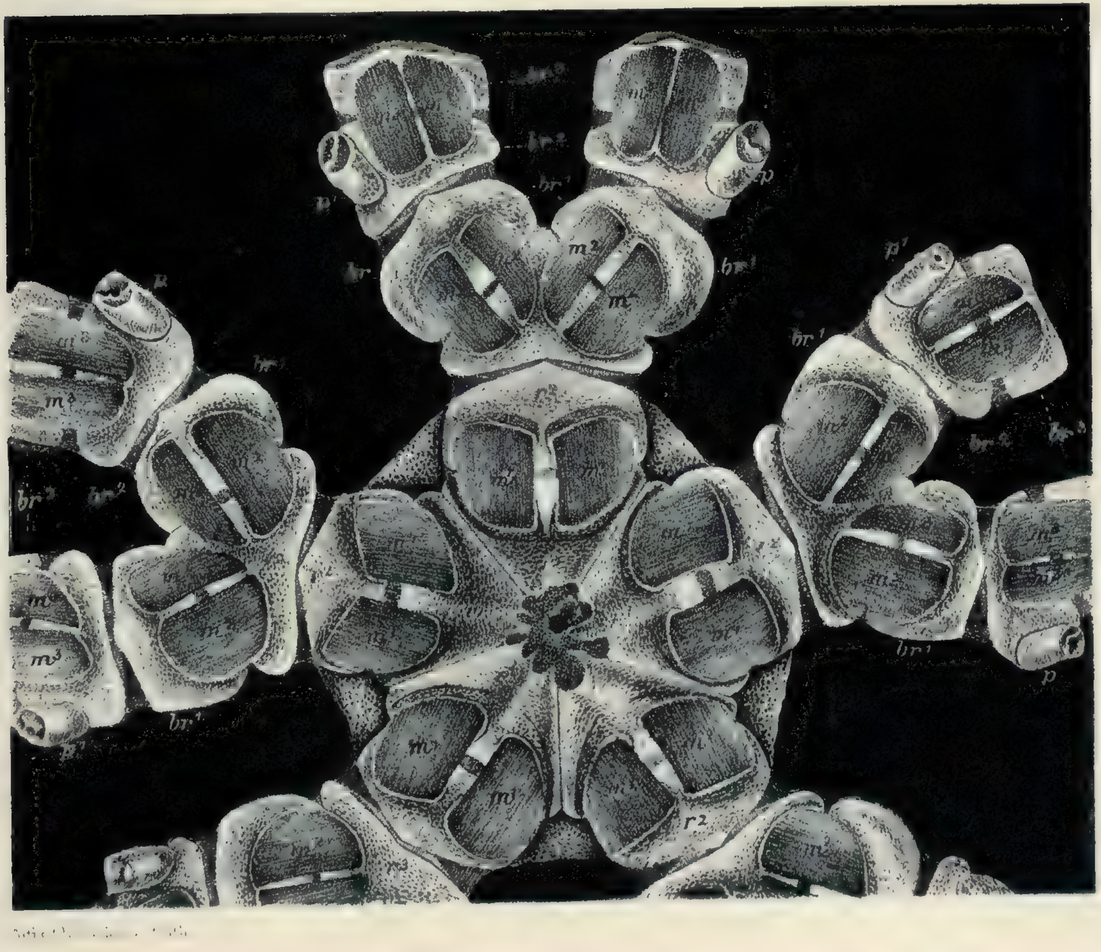
Harrison & Sons St Martins Lane.

Lens Aldous lith

1


br²
br¹
br²
br²
br¹
br¹
a
b
b
b
b
b
a
a

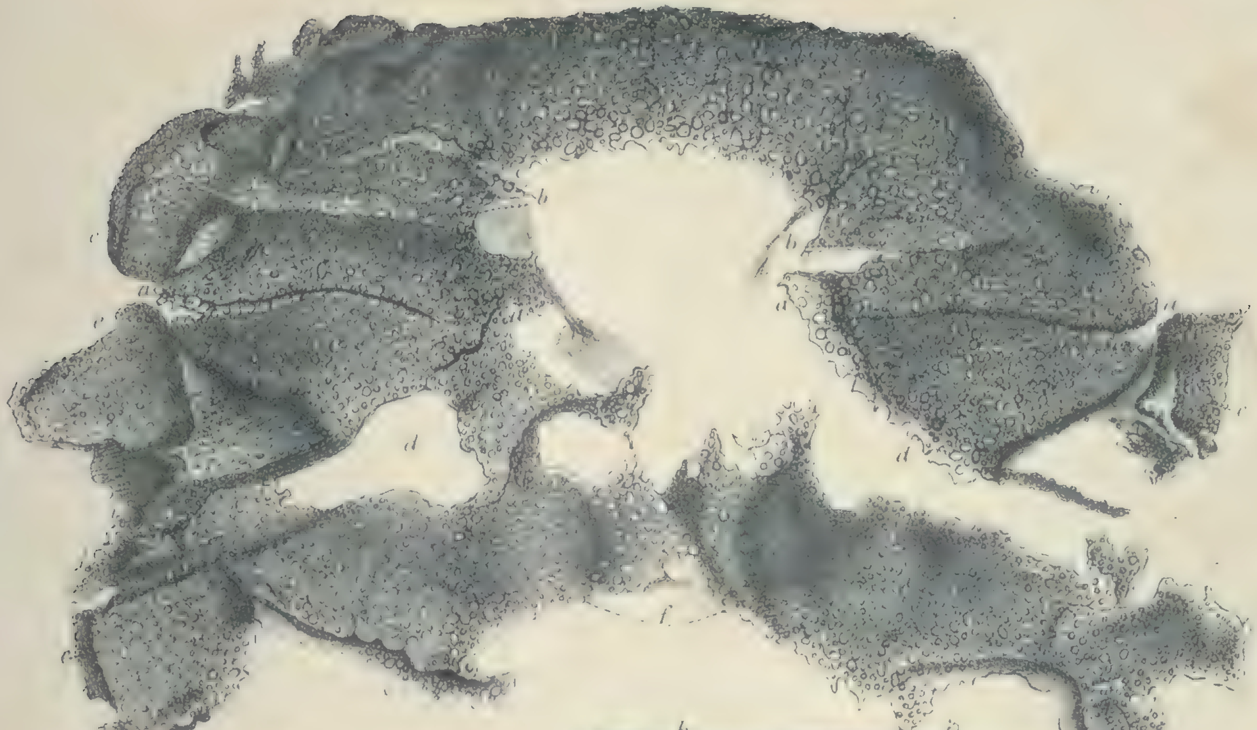
2

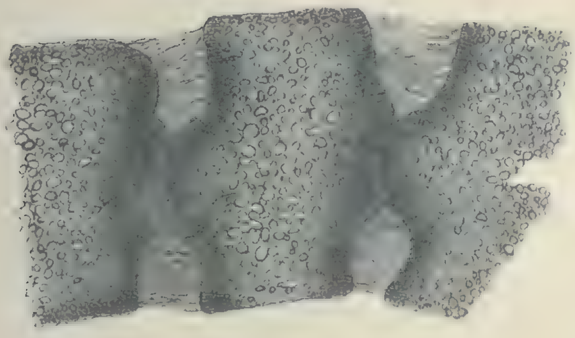

m²
br²
br¹
p¹
p
m²
m¹
br¹
br¹
p
p¹
m³
br¹
br²
br³
m¹
m¹
br¹
br²
br³
m³
m²
m³
m²
br¹
p
p¹
br¹
m¹
m¹
r²
m²

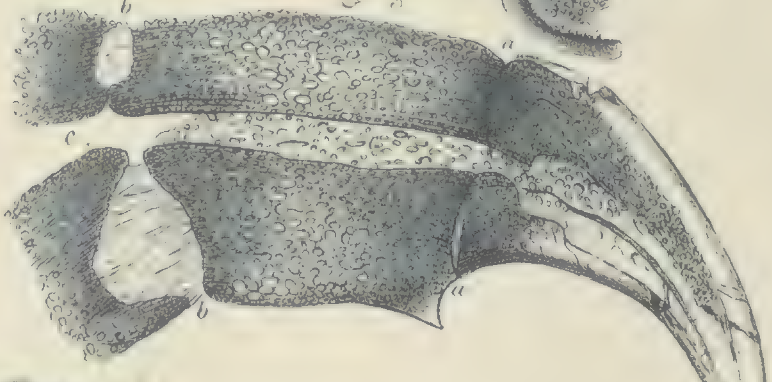
[illegible]

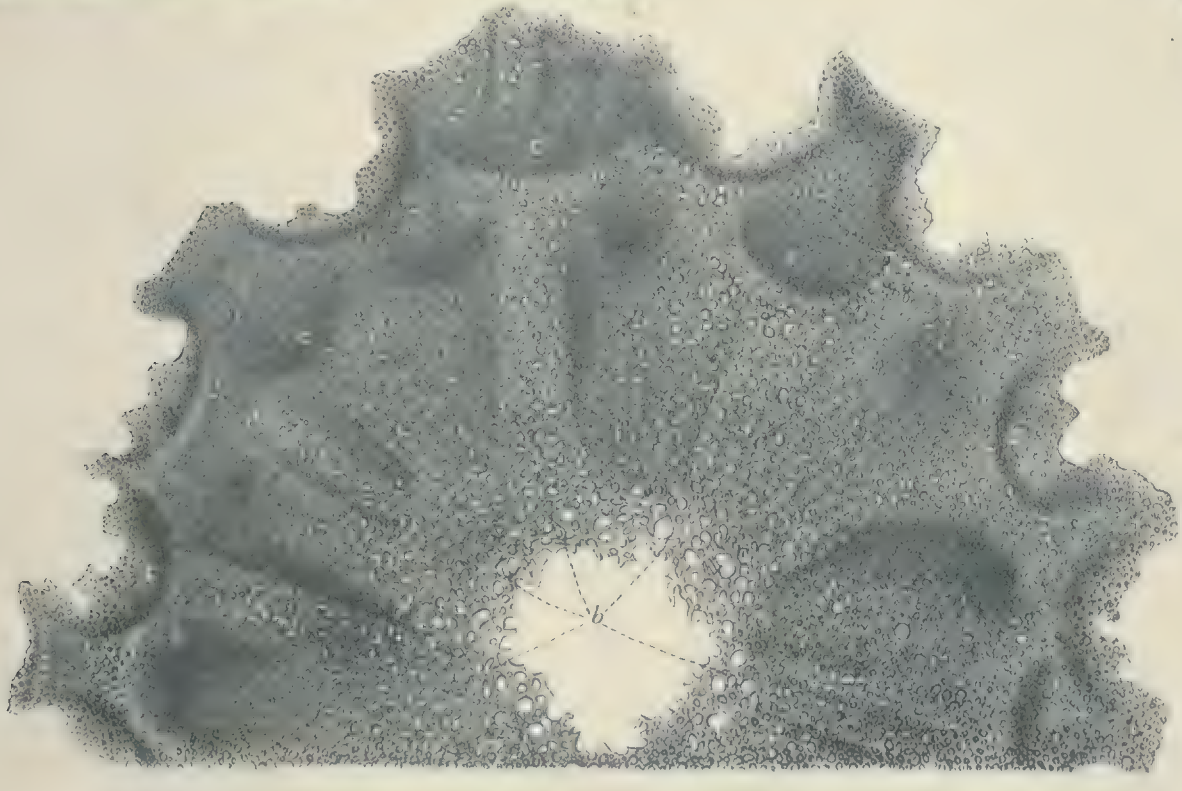
W

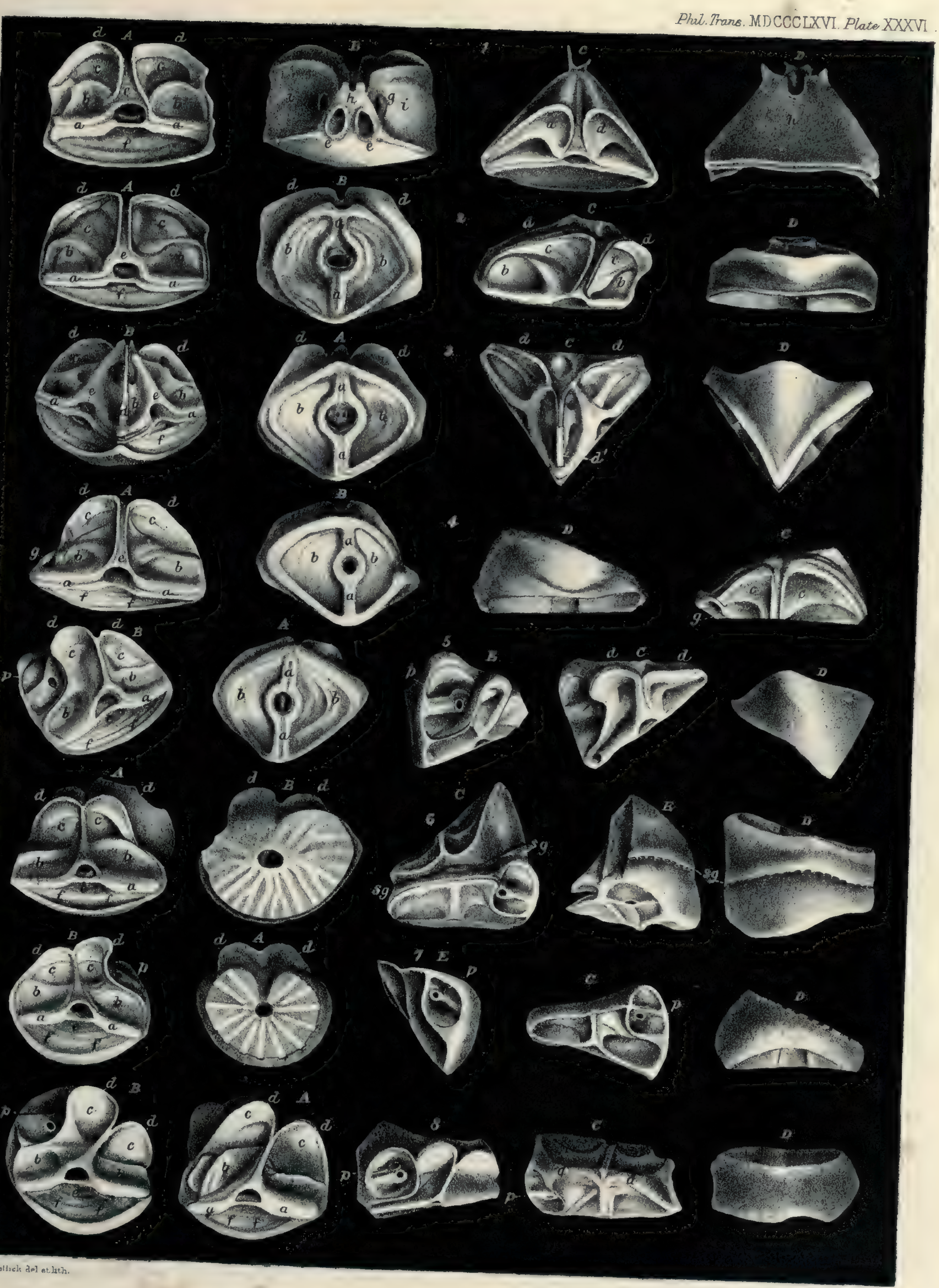
1



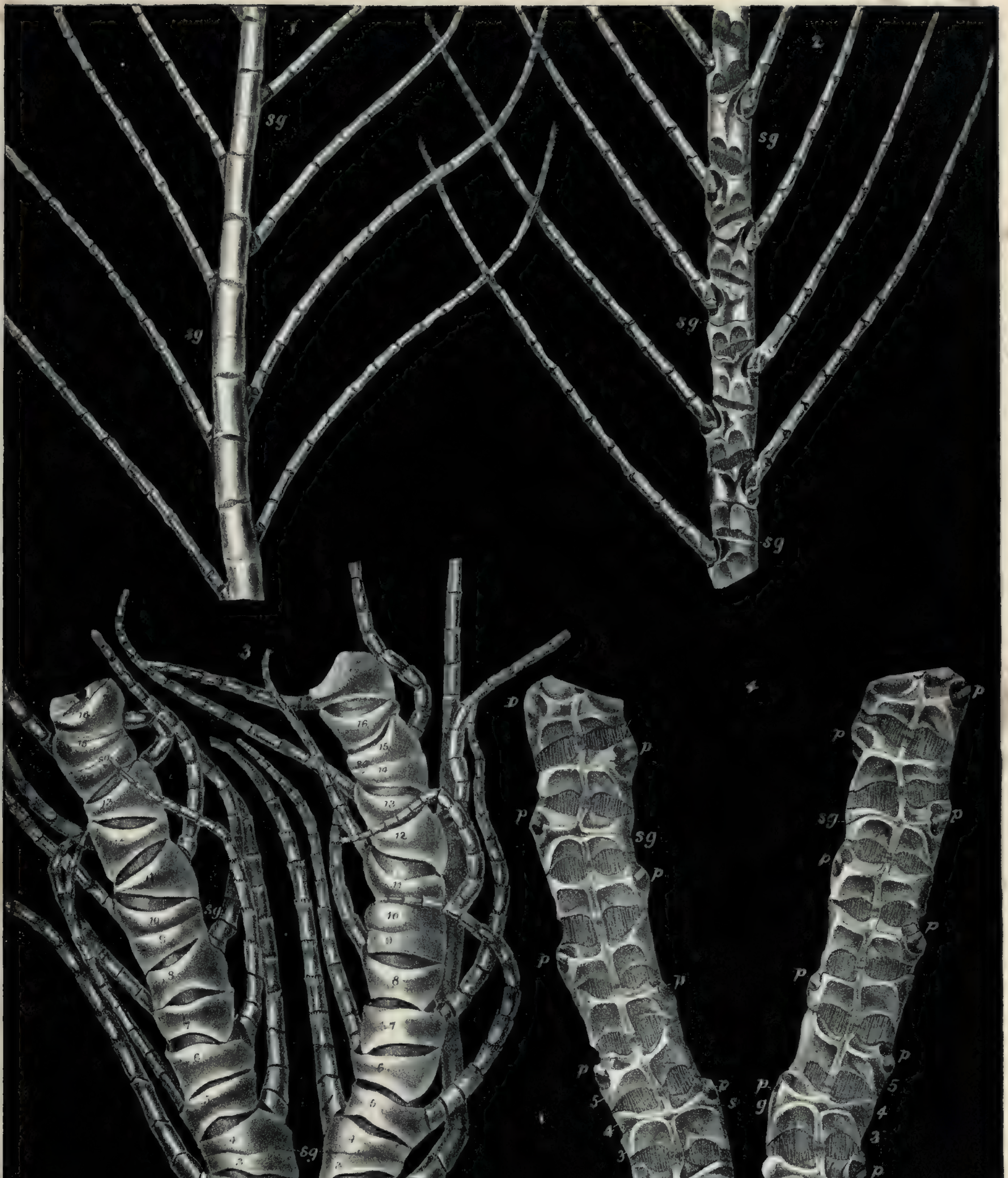




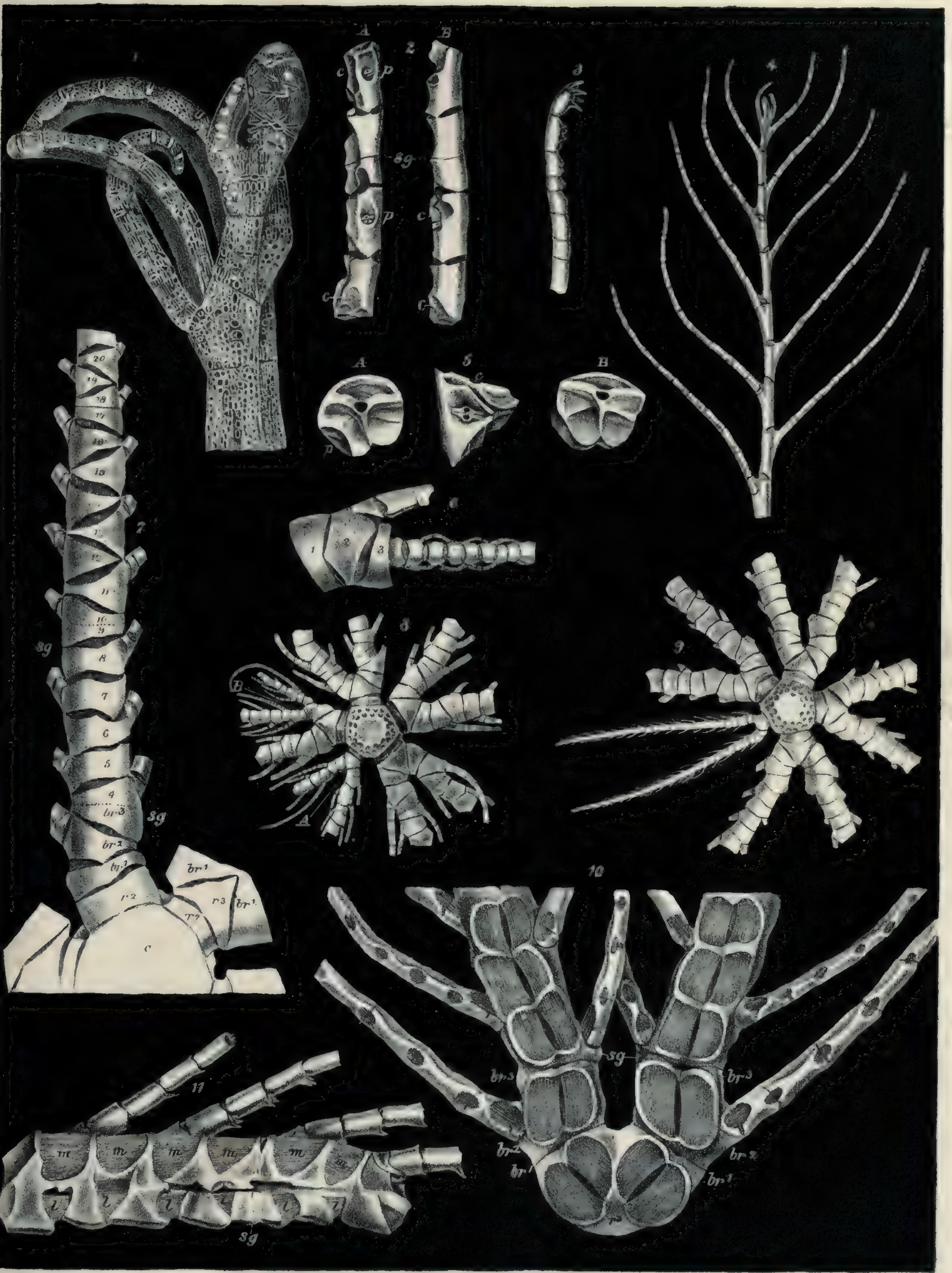




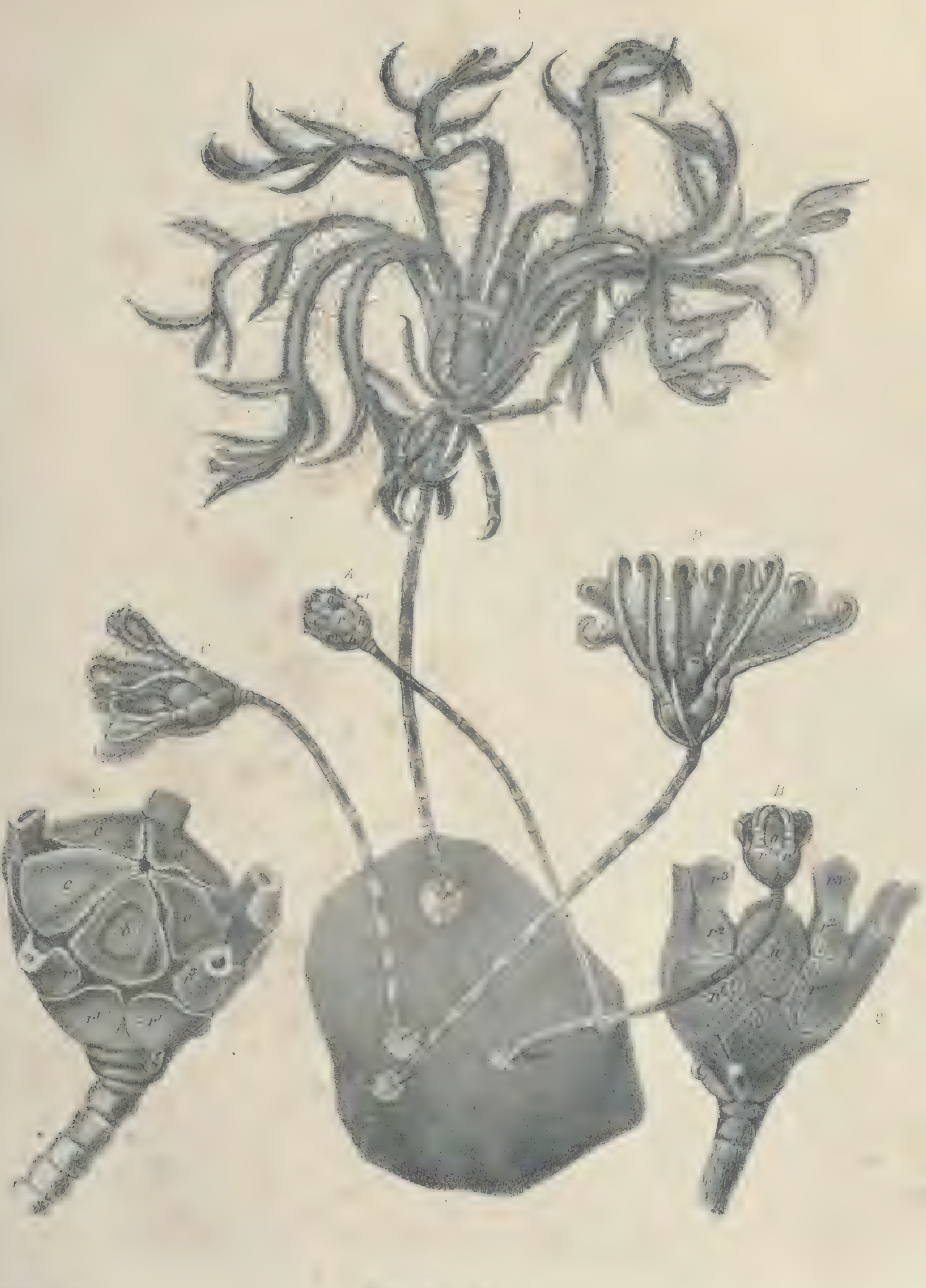
Alfred Hollick del et lith.



Alfred Hollick del et lith.

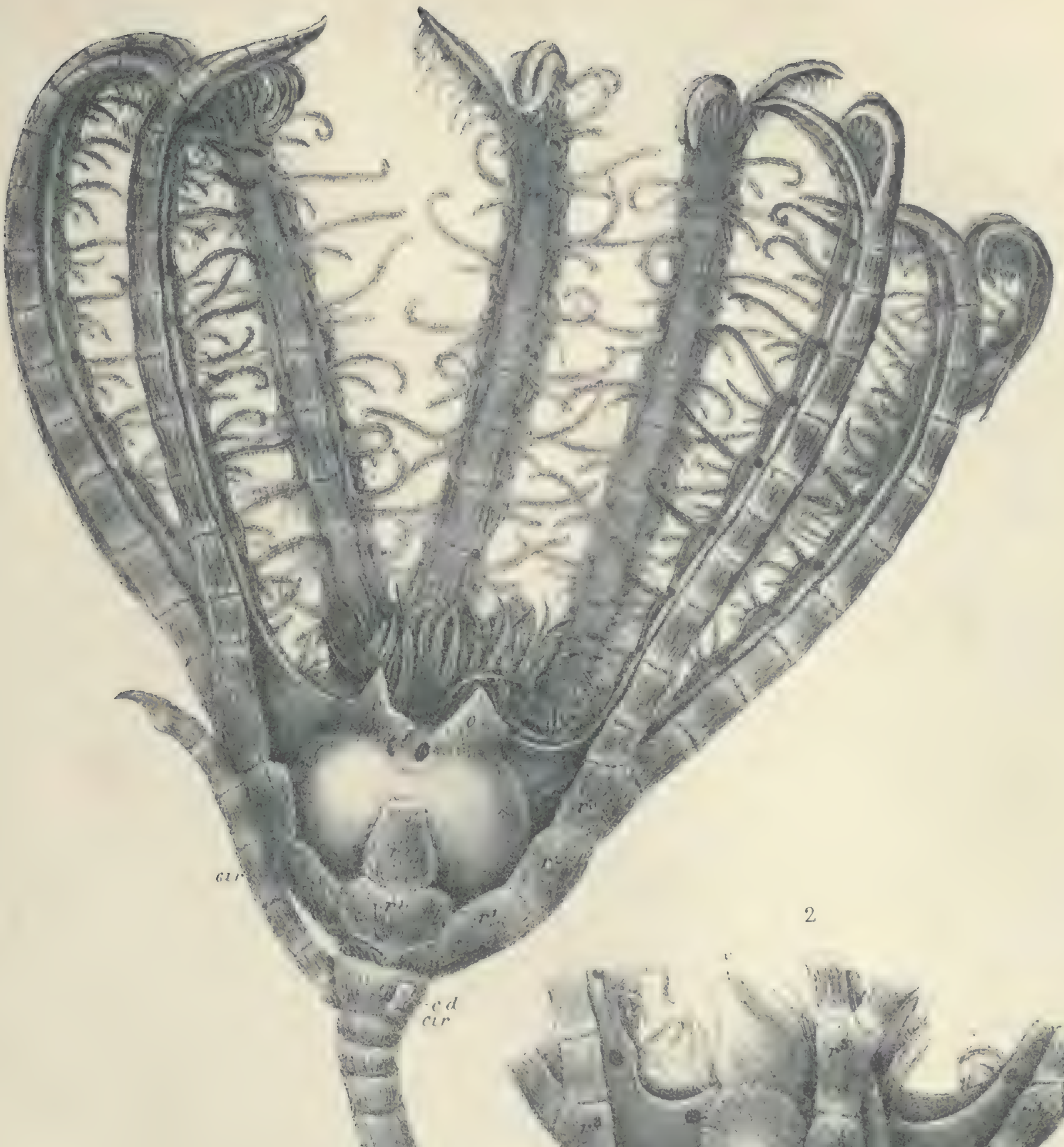


Alfred Hollick, del et lith

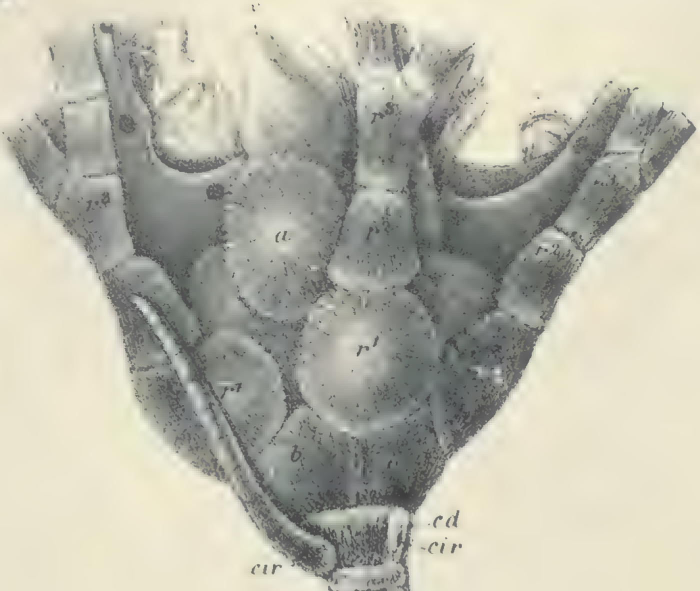


W. del.   Harrison & Sons, St Martin's Lane.   Lens Aldous lith.

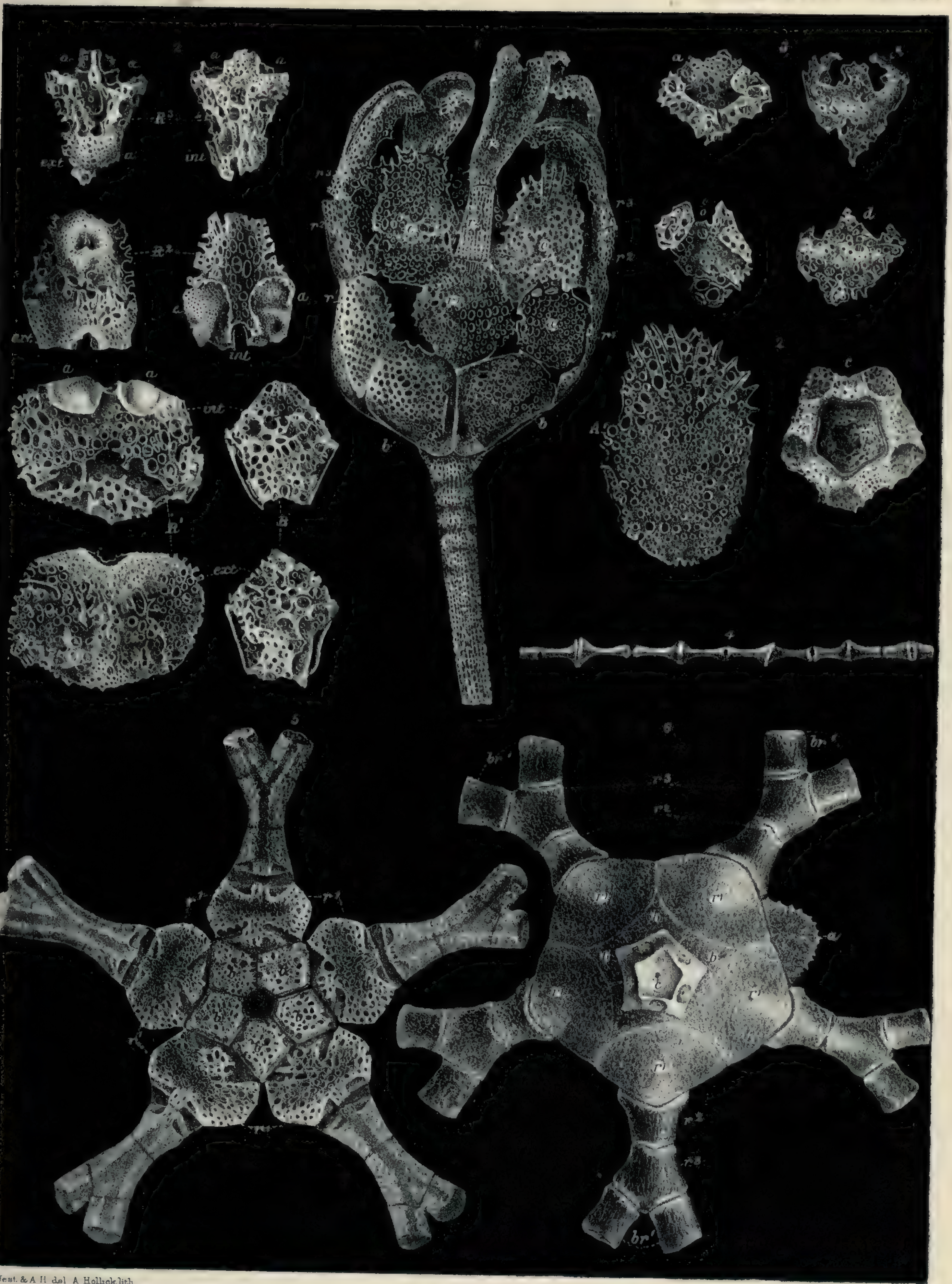
1



2

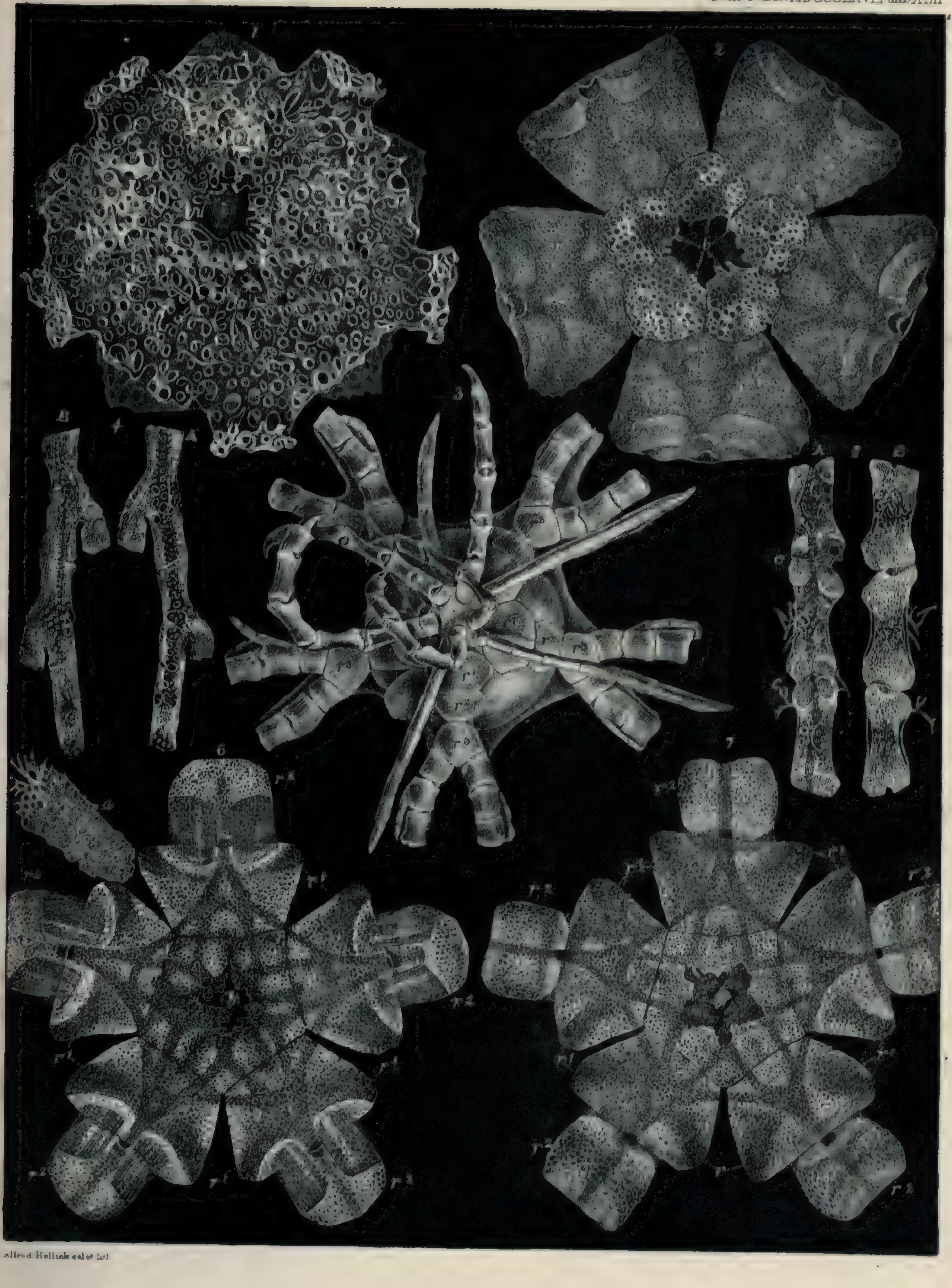


George West del.
Harrison & Sons St Martin's Lane
Lens Aldous lith.



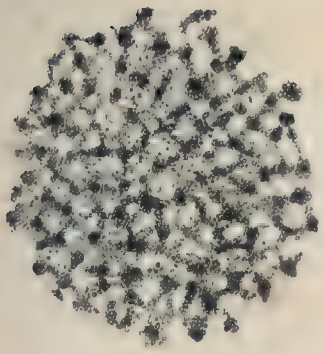
G. West. & A H del A Hollick lith

Phil. Trans. MDCCCLXVI. Plate XLII.

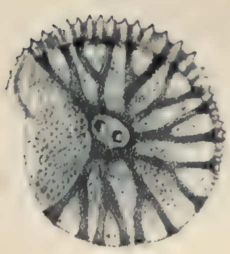


Alfred Hollick del et lith.

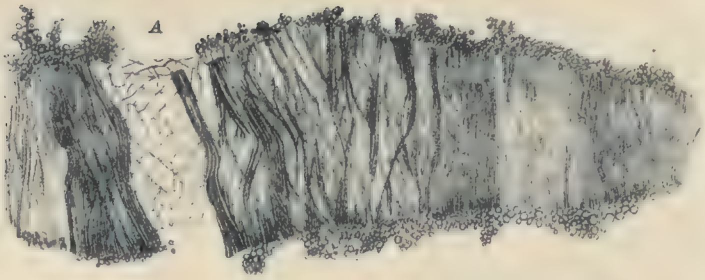
1



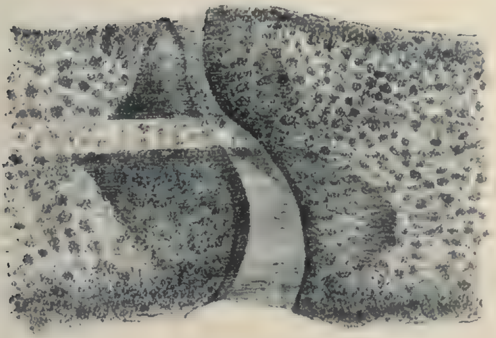
2



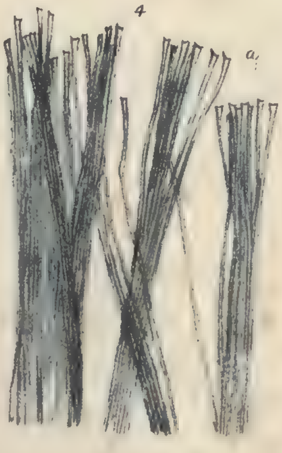
3



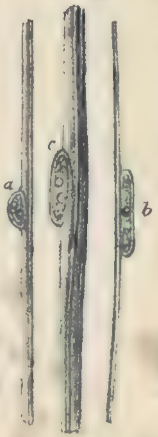
5



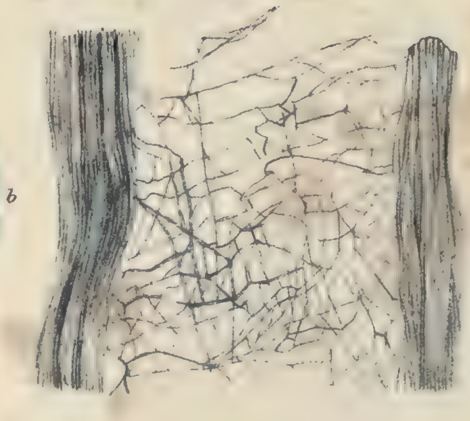
4



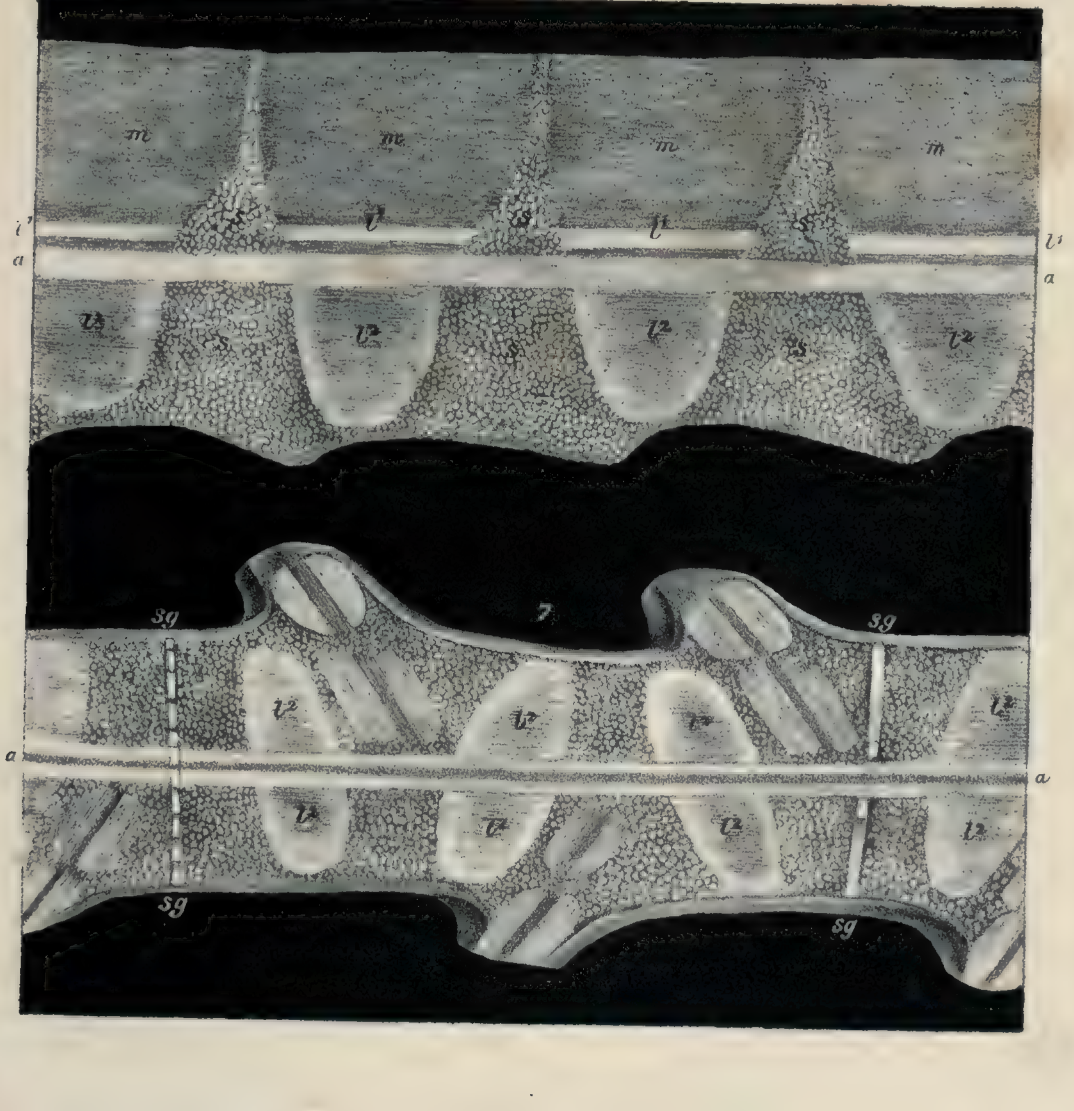
A



3A



6



Alfred Hollick, del et lith

BINDING DEPT. DEC 27 1962

Q Royal Society of London
41 Philosophical
L8 transactions
v.156
Physical &
Applied Sci.
Serials

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY